91602
new 82-10

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if Reproduced in Whole or in Part

SMOKE AND SOOT CONTROL IN BUILDINGS HOUSING METALCLAD SWITCHGEAR

Report No. 87-309-K

Reinhard Filter, Engineer,
Electrical Testing & Development Sect
Electrical Research Department

Tom Jarv, Scientist,
Environmental Science Section,
Chemical Research Department

ABSTRACT

A new design of transmission station metalclad switchgear building has been tested at the Ontario Hydro Research Division to assess improvements in smoke and over-pressure control during arcing faults. Switchgear building design enhancements included a false ceiling, a new ventilation system design, and metalclad switchgear sealing. It was demonstrated, using a full-scale building mock-up, that the new building design, the proposed ventilation system, and metalclad sealing are effective in limiting smoke and over-pressure effects on sections of switchgear not involved in the fault. It was also demonstrated that the new TS switchgear building design can quickly clear smoke from corridors and hallways to allow rapid and safe access to personnel for post-fault clean up.

job	file	date	report no.
14-204-433	813.16	April 5, 1988	87-309-K

91602
new 82-10

ontario hydro
research division

EXECUTIVE SUMMARY

SMOKE AND SOOT CONTROL IN BUILDINGS HOUSING METALCLAD SWITCHGEAR

R. Filter
Electrical Testing & Development Section
Electrical Research Department

T. Jarv
Environmental Science Section
Chemical Research Department

Smoke, soot and pressure rise attendant to arcing faults inside metalclad switchgear compartments can cause prolonged station outages and can increase the severity of fault damages. Over 75 tests at the Ontario Hydro Research Division laboratories were carried out between August 1986 and July 1987, to investigate methods of limiting the damages caused by arcing faults inside metalclad switchgear. Ventilation system enhancements proposed by the Ontario Hydro Stations and Transmission Design Department involving the use of a specially designed false ceiling, associated ducting, fans, and sealing of the switchgear were assessed with simulated and actual faults inside a transmission station building mock-up.

Test results demonstrate that the new ventilation system design, along with metalclad sealing, can be effective in limiting smoke and soot propagation through a transmission station building during and immediately after an arcing fault. With the newly developed false ceiling design, improved personnel safety is provided through better control of hot toxic gases and aerosols resulting from an arcing fault. With the new ventilation system, rapid access to corridors and metalclad sections is possible so that clean-up after a fault can proceed almost immediately.

It is concluded that the false ceiling, ventilation system enhancements, and switchgear sealing are effective and can be immediately applied.

job	file	date	report no.
14-204-433	813.16	April 5, 1988	87-309-K

GENERAL INDEX

	Title	Page
1.0	INTRODUCTION	1
2.0	SMOKE CONTROL ENHANCEMENTS	1
3.0	TEST PROGRAM PROTOCOL & OBJECTIVES	2
4.0	DATA ACQUISITION SYSTEMS	6
4.1	Smoke Detectors	6
4.2	Smoke Sampling	6
4.3	Temperatures	8
4.4	Pressure Rise Detection	8
4.5	Wall Motion Detectors	9
5.0	TEST PROCEDURE	9
5.1	Preliminary Ventilation System Tests---Commissioning	9
5.2	Smoke Tests	9
6.0	PARTICULATE DEPOSITION DENSITY (PDD)	10
7.0	TEST RESULTS & OBSERVATIONS	12
7.1	Smoke Generated Outside the Switchgear Cell	12
7.1.1	Smoke Migration Into Switchgear Cell	12
7.2	Smoke Generated Inside Switchgear Cell	16
7.2.1	Smoke Migration From and Through Switchgear Cell	16
7.3	Smoke Detectors	18
7.4	Arcing Tests	19
7.5	Test Performance Comparisons	20
7.6	The Electrical Significance of PDD	20
7.7	Smoke Particle Size	21
7.8	Pressure Rise	22
7.9	Wall Motion	25
7.10	Smoke Clearing Times	25
7.11	Noise	27
8.0	OTHER SIMILAR TESTS	27
9.0	CONCLUSIONS	28
9.1	Smoke Migration	28
9.2	Smoke Detectors	28
9.3	Smoke Clearing Times	28
9.4	Audible Noise	28
	REFERENCES	

APPENDICIES

Appendix A: Test Protocol..... 32
Appendix B: Lay-out, Fans, Ducting & Commissioning.... 36
Appendix C: Table of Test Results..... 45
Appendix D: Energy Considerations..... 46

INDEX TO FIGURES

Figure	Title	Page
1	New Ventilation System Design.....	2
2	Test Design.....	4
3	Photos of Structure Chambers and Compartments.....	5
4	Installed Smoke Detectors.....	6
5	Transducer Locations.....	7
6	Aerosol Monitor.....	8
7	Reductions in 60 Hz Withstand With PDD.....	11
8	The Effect of Ventilation System Status--No Current.....	15
9	The Effect of Ventilation System Status--3 kA/No Filters.	15
10	The Effect of Ventilation System Status--3kA/Filters.....	15
11	False Ceiling Pressure Rise--26 kA 3 Phase Arcing Fault..	23
12	Bus Compartment Pressure Rise--26 kA 3 Phase Arcing Fault.....	23
13	Calculated and Observed Pressure Rise in Bus Compartment.....	24

INDEX TO TABLES

Table	Title	Page
I	Smoke Migration Into Switchgear Cell.....	14
II	Smoke Migration Through Switchgear Cell.....	17
III	Smoke Detector Performance.....	18
IV	Results of Arcing Tests.....	19
V	The Electrical Significance of PDD.....	21
VI	Particle Size and Elemental Analysis of Aerosols Collected During Smoke Tests.....	22
VII	False Ceiling Wall and Floor Motion in Response to Arcing Faults.....	25
VIII	Front Hall and False Ceiling Smoke Clearing Times.....	26
IX	Audible Noise Recordings During Single Phase Arcing Faults in Bus Compartment.....	27

To

ontario hydro
research division

To: Mr. J.H. Midgley
Design & Development Division - Transmission
Transmission Stations Design

SMOKE AND SOOT CONTROL IN BUILDINGS
HOUSING METALCLAD SWITCHGEAR

1.0 INTRODUCTION

Many transmission stations have transformer breakers and associated switchgear housed in a single large room. With this arrangement, there are four transformer breakers, each feeding seven to eight feeder breaker cells. Recently, a fire at Slater TS and King Edward TS in Ottawa generated significant amounts of soot and smoke, precipitating switchgear cell failures, and resulting in a lengthy station outage. In these cases, the metalclad switchgear was of an older design utilizing limited convective cooling with little or no facility provided for containing arcing by-products during failure, or for controlling arcing by-products should they make their way into other switchgear cells.

A number of newer station metalclad buildings have general purpose ventilation systems which attempt to address the problems introduced by arcing by-products during failure. Even so, these ventilation system designs are still centred on heat removal and not on smoke and soot control. In most new stations, partition walls, together with station ventilation systems for smoke removal, are utilized to limit smoke damage and outage durations.

The Ontario Hydro Stations Design Department developed an approach utilizing a false ceiling design, a new ventilation system, and metalclad switchgear sealing to reduce equipment damage resulting from a fault inside the TS building. These design improvements were also intended to quickly clear smoke from the building and thereby result in rapid and safe access to the building for post-fault cleanup. Tests were initiated at the Research Division to evaluate this new TS building design and to confirm that presently used partition walls can be eliminated.

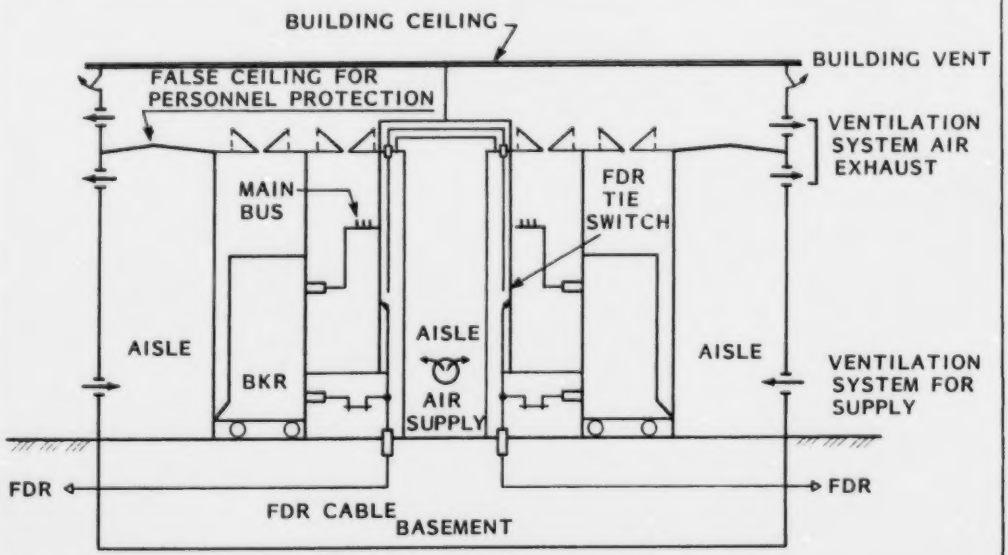
This report presents the results of that test program carried out at the Research Division during 1986 and the summer of 1987. In general, it was shown that the proposed new design of ventilation system was

effective in controlling the propagation of smoke and soot. The double ceiling feature, an integral part of the new ventilation system design, proved to be effective in containing smoke and in providing enhanced protection for personnel in TS building corridors, should a fault occur.

2.0 SMOKE CONTROL ENHANCEMENTS

Figure 1 presents a cross-section of a new switchgear room design incorporating a false ceiling and a newly designed ventilation system. This approach to station ventilation and fault by-product containment is designed to meet the objectives of protecting equipment and personnel from smoke and allowing safe and rapid station clean-up after an arcing fault has occurred. Features of this new ventilation and containment system include:

(i) double ceiling to enhance equipment and personnel protection during arcing faults by collecting and venting arcing by-products.
(ii) supply and exhaust fans, including ducting and circuitry.
(iii) smoke detectors to trigger supply and exhaust fans to create a positive pressure in the aisle areas and a negative pressure in the false ceiling to control smoke flow.
(iv) sealed switchgear cells for 1200 A applications, or, for higher ampacity cells, filters in the cell doors (for convective cooling), or cells with ventilation in the top only.



SECTION VIEW OF SWITCHGEAR ROOM (PROPOSED)

FIGURE 1: New Ventilation System Design

3.0 TEST PROGRAM PROTOCOL & OBJECTIVES

To verify that the proposed approaches to smoke and soot control are viable and will result in safety improvements, over 75 tests, using a facility incorporating as many of the design features as practical, were conducted as follows:

(i) a scaled down model of a representative section of a metalclad switchgear building including a Brown Boveri Corporation (BBC) metalclad cell with a breaker compartment (and breaker), a bus compartment (with buswork and bushings), and a cable compartment was constructed. The test structure also included a false ceiling, front, back and side corridors, along with additional corridors to allow viewing of the tests. All test facilities were constructed to demonstrate:

(a) that the ventilation system providing the cross flow and pressurization can be commissioned to operate as designed,

(b) that little or no smoke is detected in the aisles below the false ceiling during and after a fault,

(c) that little or no smoke is detected inside any cell when the smoke is generated outside the cell.

Assessments of the new design of ventilation system were divided into three types of tests. First, the test set-up was commissioned to confirm ducting and fan performance. Secondly, tests without load current were carried out with commercially available smoke candles to generate smoke in switchgear and station mock-up compartments to assess the transportation of smoke throughout the set-up. Finally smoke migration tests including the effects of load current and additional heating to bring switchgear compartments to typical operating temperatures/1,2/ were conducted.

Confirmation tests using single and three phase fault arcs in the false ceiling and inside the metalclad bus compartment were carried out after all smoke tests with smoke candles were completed to verify that test results with smoke candles were similar to test results with actual fault arcing. In addition, tests involving arcing faults also allowed an assessment of the pressures generated inside the metalclad during arcing faults, and therefore an assessment of structure response to arcing faults. During the arcing tests, an opportunity was available to assess the efficacy of the Ontario Hydro developed Fault Current Diverter, a device to dramatically limit energy release during arcing faults. Tests results and performance of the Fault Current Diverter in this application are presented in a companion report/3/ on this subject. Figure 2 below presents the test protocol for ventilation system assessments.

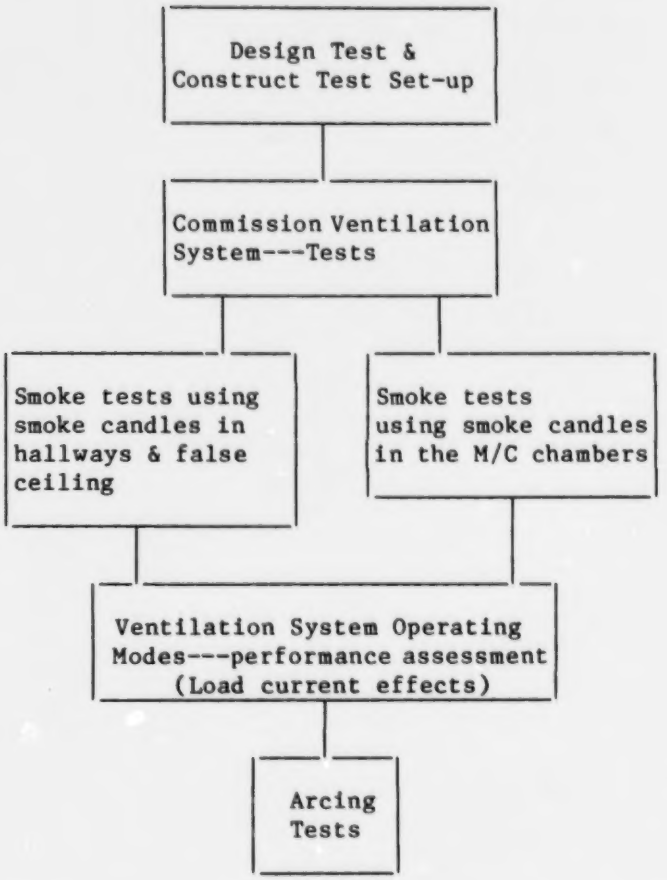


FIGURE 2: Test Design

Photographs of the test set-up are shown in Figure 3.

In tandem with the testing conducted at the Ontario Hydro Research Division, smoke penetration studies were carried out at Overbrook TS to assess the smoke handling facilities installed there. The results of those tests are also presented in a companion report/4/.

FALSE CEILING

FRONT HALL

REAR HALL

FIGURE 3:
Photos of Structure Chambers and Compartments

Appendix A presents the step-by-step test procedure and appendix B provides test set-up lay-out and ducting drawings.

4.0 DATA ACQUISITION SYSTEMS

To assess ventilation system performance, smoke penetration into the cubicles and hallways, as well as system response to arcing faults was tested. Smoke detectors, smoke sampling systems, and pressure transducers were installed to acquire performance data.

A central data gathering facility was established near the mock-up so that simultaneous transducer responses could be recorded. Smoke detector response times, pressure rise in the mock-up chambers, and arc characteristics were measured on oscillograph recorders. Temperature data was recorded on a datalogger. Smoke penetration and real-time smoke migration through the structure were measured using a computerized data acquisition system manned by staff from the Chemical Research Department.

4.1 Smoke Detectors

Figures 4 and 5 show the smoke detector arrangement and locations during this series of tests.

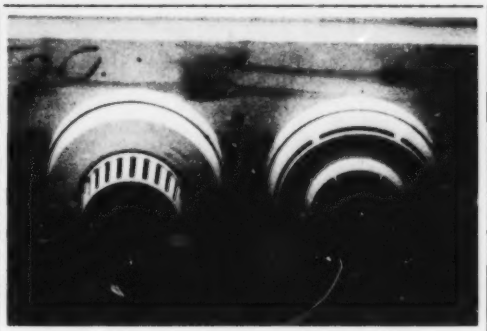


FIGURE 4:
Installed Smoke Detectors

Two types of smoke detectors, photoelectric detectors and ionizing detectors were installed at each smoke detector location. In all cases, the detectors were mounted close together so that they would be exposed to the same amount of smoke during the tests. Smoke detectors manufactured by Pyrotronics (models #PEC-3 and DI-3) were used throughout these tests. These detectors were previously tested at Research Division and were recommended/5/.

4.2 Smoke Sampling

Six samples of airborne smoke particles were collected using filter packs during each test. Filter pack locations are shown in Figure 5. Each air sampling location was equipped with a 47 mm diameter Millipore HAWP 04700 0.46 µm pore size filter that had been previously weighed. The filter was set into an open faced filter holder which was mounted about 1.5 m above the floor level in the hallways and ceiling and near the center of each metalclad compartment. Polyethylene tubing (9.53 mm OD) was run from each filter pack to a calibrated sampling pump. After each smoke test, the filters were removed and stored in plastic dishes until the final weights could be obtained.

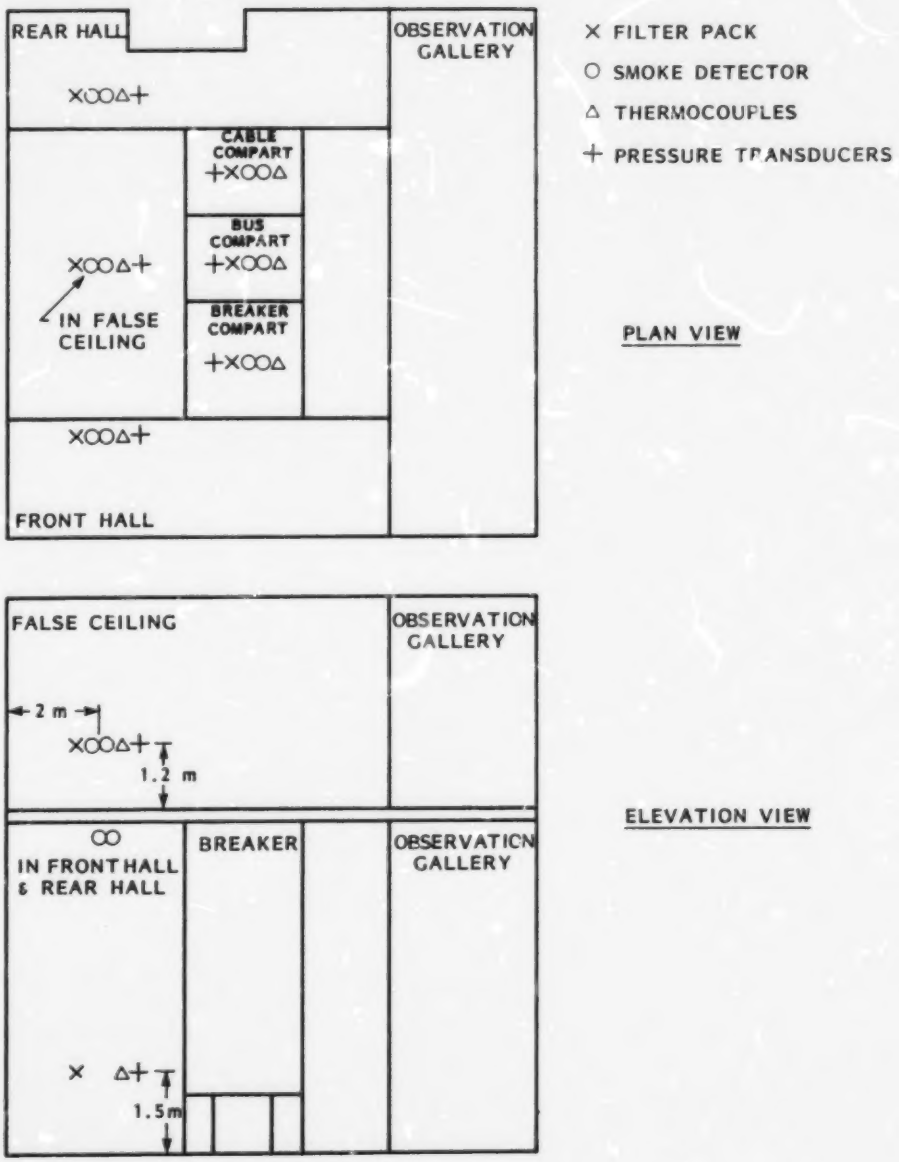


FIGURE 5:
Transducer Locations

A Baush & Lomb Model 40-1a aerosol monitor was set up in a room adjacent to the metalclad switchgear (see figure 6). A one metre piece of 9.53 mm ID Tygon tubing attached to the monitor inlet was inserted into one of the metalclad compartments during testing. The monitor output was recorded by a HP3497A data-logger under software control from an HP 87XM microcomputer. Single channel particle concentration measurements were made at a median particle size of 2 μm.

FIGURE 6: Aerosol Monitor

4.3 Temperatures

Figure 5 shows the location of the thermocouples used to determine the temperatures inside the cubicles and hallways during the tests. This information was useful in assessing the performance of the fans and ducting.

4.4 Pressure Rise Detection

During arcing tests, assessments of pressure rise in several of the locations throughout the structure were made using low pressure transducers. Figure 5 shows pressure transducer locations throughout the mock-up.

4.5 Wall Motion Detectors

In addition to pressure rise assessments, and to provide input into building design, measurements were made of the response of the mock-up structure walls to the overpressure created by an arcing fault.

5.0 TEST PROCEDURE

5.1 Preliminary Ventilation System Tests---Commissioning

Ventilation tests were carried out with the ducting and fans in the mock-up to confirm that fan and ducting performance was satisfactory prior to the commencement of smoke testing.

Appendix B presents the results of the these initial tests.

5.2 Smoke Tests

Tests involving the generation and propogation of smoke were divided into two categories, (i) tests involving the use of smoke candles to generate smoke, and, (ii) tests with arcing faults to generate smoke.

First, because many tests were required to determine the movement of smoke through the test set-up, smoke tests using smoke candles (ie. no arcing) were carried out. These tests allowed assessment of the ventilation system performance, the efficiency of sealing, and the effect of metalclad filters under a variety of conditions without damaging the set-up. Smoke was produced for several minutes and then permitted to disperse through the structure for up to five minutes.

In this first series of tests with smoke candles, three operating conditions were simulated. Tests were carried out with the switchgear at ambient temperature. This modeled the situation where the switchgear had been isolated and unenergized for some time. Then, tests using smoke candles were carried out with the rated 1200 A circulating through the switchgear bus and breaker assemblies. This modeled the type of heating produced during normal operating conditions. Finally, tests were carried out with smoke candles when 3000 A switchgear performance was being assessed. This last testing was done by circulating the rated 1200 A through the switchgear buswork and then supplementing the heating produced by rated current with additional heaters to bring internal switchgear cell ambient air temperatures to levels previously observed during other in-situ thermal assessments of similar metalclad switchgear/1,2/.

The test procedure followed, the location of the candles during each test, plant settings (ie, fan status, damper settings, duration of smoke generation, etc), and the criteria used in the performance assessments are presented in Appendix A.

The second category of tests used high current arcs and simulated smoke

migration when the metalclad is energized. Initially, several single phase high current arcs were produced in the false ceiling to assess ventilation system and mock-up structure response to arcing faults. Then, a three phase high current arc of 26 kA lasting 10 cycles was initiated inside the bus compartment of the metalclad structure to assess system response to a full three phase fault, and to compare the amount of smoke produced with that produced by a single phase arcing fault.

All testing using high current arcing faults also permitted the assessment of pressure rises accompanying such faults.

To supplement the testing with smoke candles and arcing faults, a series of tests were conducted with burning epoxy and arcing in the presence of polyethylene. These last tests confirmed that the smoke behavior observed with smoke candles, and with the relatively clean burning high current arcs, accurately represented "real life" behaviour.

6.0 PARTICULATE DEPOSITION DENSITY (PDD)

One objective of this test program was to determine whether significant pollution from smoke associated with arcing faults is deposited on unaffected bus structures. For indoor switchgear, such as the metalclad included in this test program, the bus itself is often covered to provide insulation and protection from the environment. Bus support structures such as stand-off insulators usually contact only the bus covering so that insulation compromise from pollution is not likely to be a major potential problem. However, at critical points, such as the breakers, parts of the current carrying path can be exposed to the environment, and may therefore be compromised by the deposition of pollution resulting from a fault.

Determining the effect of smoke pollution on exposed, air insulated, high voltage components is a difficult task since little research has been done in this area. However, considerable testing has been carried out on the effects of salt on high voltage insulators/6/, and it is possible to develop an analogous parameter to the Salt Deposition Density commonly used to assess insulator pollution. The new parameter, in this case applied specifically to the case of soot deposition on exposed high voltage insulation, has been called the Particulate Deposition Density.

The Particulate Deposition Density (PDD) is the amount of contaminant deposited on a spherical surface surrounding a known volume of air from which smoke is collected.

To determine the electrical significance of PDD values, 60 Hz flashover tests were carried out with 37 glass surfaces (test tubes) polluted with known amounts of carbon soot. Figure 7 presents the relationship between PDD and the reduction in insulation strength of the polluted surface. This relationship may be used as an indicator of the

electrical consequences of carbon soot on insulator surfaces.

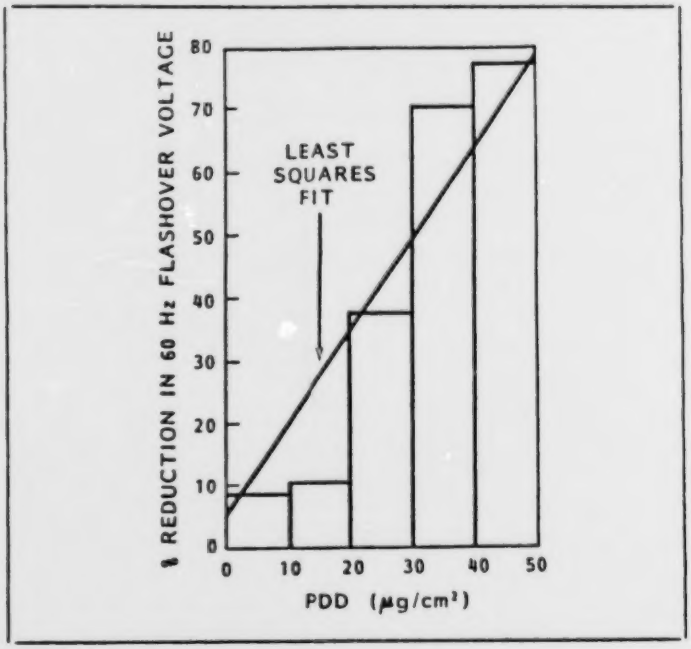


FIGURE 7:
Reductions in 60 Hz Flashover With PDD
(Carbon Soot Pollution)

In Figure 7, percent reductions in 60 Hz flashover voltage resulting from carbon soot deposition are presented. An important distinction must be made between the data provided in Figure 7, and potential reductions in 60 Hz withstand voltage resulting from carbon soot deposition. Manufacturers design metalclad switchgear to withstand applications of high voltage for one minute considerably in excess of rated line to ground voltage. For the case of the 15 kV class switchgear included in this test program, a one minute, 60 Hz withstand level of 36 kV is required by the standards. The reductions in flashover voltage presented in Figure 7 do not necessarily indicate corresponding reductions in 60 Hz withstand voltages. To illustrate this point, consider that for a particular piece of equipment, it has been demonstrated that the standard requirement of a 60 Hz withstand voltage of 36 kV for one minute has been met. Suppose that design testing has shown that this piece of equipment has support insulators for which 60 Hz flashover is known to occur at 45 kV. Suppose further that a fault has occurred near the equipment and deposited soot to a PDD level of about 9 micrograms/cm^2. Then, from Figure 7, flashover reductions of about 18% are probable. This translates to the equipment having a flashover voltage of about 37 kV instead of 45 kV. This means that the performance margins originally designed into the equipment will have

been significantly reduced, even though, in this case, the 60 Hz withstand requirement specified by the standards can still be met.

In other more extreme cases of soot pollution, reductions in 60 Hz flashover voltages may result in compromises of the rated 60 Hz withstand strength of the equipment, however, without additional more detailed design data pertaining specifically to the equipment under assessment, it is not possible, in general, to quantify precisely whether or not particular PDD values would reduce 60 Hz withstand from required levels.

7.0 TEST RESULTS & OBSERVATIONS

7.1 Smoke Generated Outside the Switchgear Cell

In the following, the principal observations for the tests where smoke was generated with smoke candles outside the metalclad structure are summarized. Specific test results and observations for this test series is available in Appendix C.

7.1.1 Smoke Migration Into Switchgear Cell

Table I and Figures 8-10 present test data for smoke generated with smoke candles. The results of varying the plant settings (ie filters and sealing, unloaded and loaded bus, etc.) are presented. Additional test parameters (ie duration of smoke generation, specific PDD values etc.) are available in Appendix C. The following observations can be made:

7.1.1.1 For no current tests and 1200 A simulations, with smoke present only in the false ceiling, smoke did not penetrate the switchgear cells or the hallways. For 3000 A simulations, small amounts of smoke were detected in the cable and breaker compartments. The false ceiling was effective in containing the smoke (ie little or no smoke penetrated the metalclad or hallways) no matter which ventilation scenario was tested, and at any breaker operating temperature.

7.1.1.2 No practical difference in observed PDD was evident between ventilation scenarios having fans running at the beginning of the test and ventilation scenarios having fans initially off but triggered by smoke detectors (see Figures 8-10).

7.1.1.3 With any ventilation system condition, smoke in the false ceiling did not consistently vent through the mock-up vent. Smoke tended to flow through the building vent only when overpressures resulting from arcing faults were present, and only when outside wind direction favoured it.

7.1.1.4 Metalclad sealing is effective in limiting smoke ingress into the switchgear cells to very low levels both during no current and 1200 A conditions. Most of the time, smoke densities inside the switchgear were low enough to prevent smoke detectors inside the switchgear cells from annunciating.

7.1.1.5 With no sealing, during the 3,000 A simulations, smoke from the hallways penetrated the switchgear cell and was passed into the false ceiling. Most of the time, more smoke accumulated in the breaker and cable compartments than in the bus compartment. In particular, PDD values for the breaker compartment during these tests varied between 1.04 micrograms/cm^2 and 1.45 micrograms/cm^2. From Figure 7, these PDD levels translate into 60 Hz flashover reductions of 5% or less.

7.1.1.6 Furnace type filters did not have a significant effect on smoke penetration into the switchgear cell from the hallways. When smoke was in the false ceiling, filters were marginally effective in limiting smoke penetration into the switchgear cell.

In general, when smoke was produced in any of the hallways, it tended to migrate through the mock-up structure and reach other hallways via cracks, seams, and bolt holes in the structure itself. On the other hand, once the smoke reached the false ceiling, it tended to remain in the false ceiling and not return to the hallways. Video tapes of the smoke in the false ceiling showed that when supply and exhaust ventilation fans were running, most of the smoke in the false ceiling flowed to the exhaust vents in the false ceiling, and out of the building. Although relatively little turbulence was evident on the video tapes of the smoke in the false ceiling when both supply and exhaust fans were running, when either system was running alone, the turbulence in the false ceiling was increased and, in general, ventilation and removal of smoke was less effective.

TABLE I: Smoke Migration into Switchgear Cell

Condition	Test Number (Append. C)	Comments
No Current (sealed breaker cell)	1,2,3 17,18 19,20 21,22 59-61	With all combinations of fan conditions, very little or no smoke was detected inside switchgear cell.
1200 A Simulation (sealed breaker cell)	32,33 34,35	Due to heating of the breaker and bus compartments, small amounts of smoke were detected inside cell. If smoke generated in false ceiling, none detected in cell. Smoke does not migrate into hallways from false ceiling
3000 A Simulation Without filters	36,37 38,39	Due to the convective cooling of breaker and bus compartments smoke of comparable density as that in the front hall, was detected inside the cell. Smoke in hallways was fed through cell into false ceiling. False ceiling smoke was detected in front and rear halls, & cable and breaker compartments. No smoke was observed coming out the building vent.
3000 A Simulation Filters	40,41 42,43	Smoke from hallways flowed through cell into false ceiling. Smoke in false ceiling did not migrate into metalclad cells.

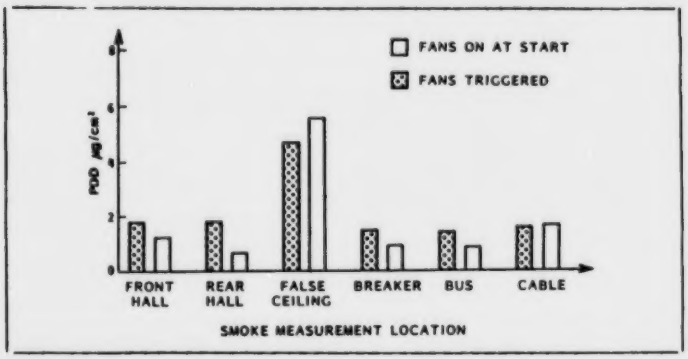


FIGURE 8:
The Effect of Ventilation System Status--No Current

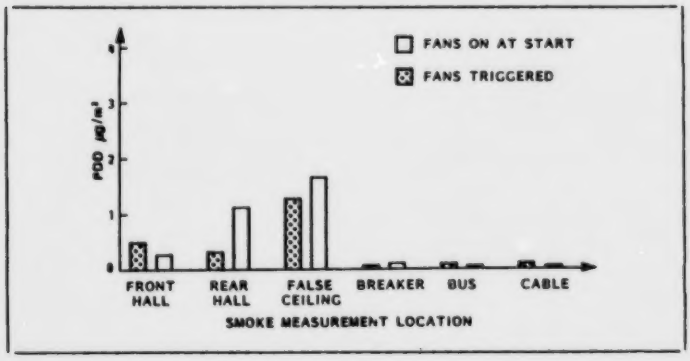


FIGURE 9:
The Effect of Ventilation System Status--3 kA/No Filters

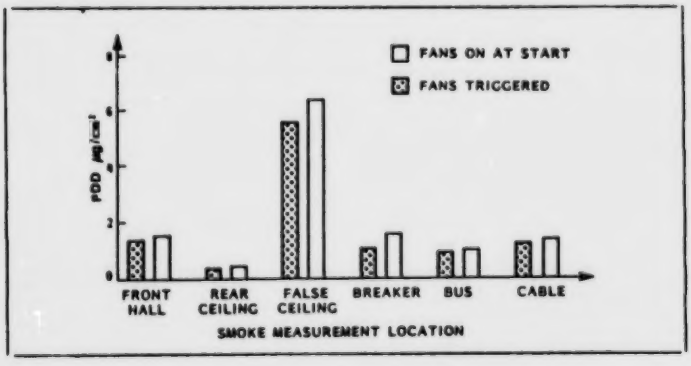


FIGURE 10:
The Effect of Ventilation System Status--3 kA/With Filters

7.2 Smoke Generated Inside Switchgear Cell

In the following, the principal observations for the tests where smoke was generated with smoke candles inside the metalclad structure are summarized. Specific test results and observations appear in Appendix C.

7.2.1 Smoke Migration From and Through Switchgear Cell

Table II represents test data for smoke migration from and through switchgear cells. The results of varying plant settings (ie. filters and sealing, unloaded and loaded bus, etc.) are included. The following observations can be made:

7.2.1.1 If there is smoke anywhere in the switchgear cell, it will penetrate the false ceiling and, to a lesser extent, the hallways.

7.2.1.2 The status of the ventilation fans at the start of the test did not affect the amount of smoke retained inside the switchgear.

7.2.1.3 As with the tests when smoke was generated outside the metalclad, when smoke was produced inside metalclad compartments, it tended to migrate through the metalclad to reach other compartments via cracks, seams, and bolt holes. Once the smoke reached the false ceiling, it tended to remain in the false ceiling and not return into the metalclad.

7.2.1.4 The effect of the switchgear filters was to (i) raise the ambient temperatures in the cell compartments, and (ii) restrict smoke ingress from the false ceiling. The filters had no effect on the flow of smoke into the metalclad from the hallways.

TABLE II: Smoke Migration Through Switchgear Cell

Condition	Test Number (Append. C)	Observations
No current (sealed breaker cell)	4,5,6,7 8,10,11 12,13,14 16,23,24 25	For all ventilation scenarios, no significant amounts of smoke escaped from the metalclad into the hallways and false ceiling. Small amounts of smoke were detected escaping from the hinge joints of the top flaps. Smoke in any compartment penetrates all compartments.
1200 A Simulation (sealed breaker cell)	26,27 28,29 30,31	Same conclusions as for no current tests. Forced ventilation triggering from hallway or false ceiling smoke detector was not possible since smoke was contained by switchgear cell.
3000 A Simulation Without Filters	50,51 52,53 54,55 56	Convective cooling directed the smoke into the false ceiling and not into the hallways. Smoke in breaker/cable comp. triggered false ceiling smoke detectors. Smoke in bus compartment did not trigger false ceiling detectors. Smoke from bus or cable comp.did not reach breaker compartment
3000 A Simulation With Filters	44,45 46,47 48,49	Smoke in cable compartment penetrated false ceiling. Smoke from breaker penetrated other compartments and flowed into false ceiling.

7.3 Smoke Detectors

In Table III below, the performance of the two types of smoke detector are compared.

TABLE III: Smoke Detector Performance

Condition	Smoke Det.	Location	# of Tests	Mean Firing Time (min)	Std. Dev. (min)	Annunciation Failures (note 1)
SMOKE GENERATED	PHOTO.	Front & Rear Hall	24	0.65	0.47	0
	ION.	Front & Rear Hall	24	0.72	0.50	0
	PHOTO.	False Ceiling	20	0.71	0.63	0
	ION.	False Ceiling	20	0.69	0.50	1
	PHOTO.	in cells	28	0.19	0.15	0
	ION.	in cells	28	0.16	0.14	2
SMOKE INGRESSED	PHOTO.	Front & Rear Hall	13	1.01	0.79	1
	ION.	Front & Rear Hall	3	2.04	---	11
	PHOTO	False Ceiling	27	1.61	1.12	1
	ION.	False Ceiling	12	1.85	1.42	16
	PHOTO.	in cells	61	1.60	1.00	3
	ION.	in cells	43	1.58	0.99	21

NOTE:

1. The number of annunciation failures is the number of times the referenced smoke detector failed to annunciate when the other detector at that location did.

The following observations may be made:

7.3.1 In areas of high smoke density, there is very little difference in the mean annunciation times of photo and ionizing type detectors.

7.3.2 In areas of low smoke density, the mean annunciation times of photoelectric detectors is somewhat faster than those of ionizing detectors. In low smoke density locations, ionizing detectors failed to annunciate more often than photoelectric detectors.

7.4 Arcing Tests

Arcing tests involving single phase and three phase fault currents were carried out in the false ceiling and in the bus compartment of the metalclad to confirm the observations obtained from tests with smoke candles.

Table IV presents the results of the arcing tests in terms of arcing pollution (PDD). For comparison purposes, the results of several tests using smoke candles have been included.

TABLE IV: Results of Arcing Tests

ARC I (kA)	LOCATION	DUR	FANS	METAL CLAD FLTRS	PDD* ($\mu g/cm^2$) FH	RH	FC	BRKR
24 single phase	False Ceiling	6 cycle	OFF	NONE	0.35	0.32	4.33	0.01
28 single phase	False Ceiling	12 cycle	OFF	NONE	0.15	0.57	5.2	0.10
26 three phase	Bus	10 cycle	OFF	NONE	0.05	0.02	4.48	1.66
FOR COMPARISON:								
COLD BUS (#8)	Bus	1 min.	OFF	NONE	0.15	0.26	0.36	0.14
HOT BUS (#30)	Bus	1 min.	OFF	NONE	0.05	0.02	0.06	2.60
COLD BUS (#70)	False Ceiling	6 min.	OFF	NONE	0.04	0.00	8.78	0.01

* Note: Locations where PDD measurements were made are coded as follows:

FH = Front Hall
RH = Rear Hall
FC = False Ceiling
BRKR = Breaker Compartment

The following observations can be made:

7.4.1 For arc generated smoke in the false ceiling:

7.4.1.1 Smoke tended to remain in the false ceiling with PDD levels 10 times higher than in the aisles.

7.4.1.2 The false ceiling was effective in containing smoke.

7.4.2 For arcing faults in the bus compartment:

7.4.2.1 A ratio of 100 or better is evident for the PDD ratios of the arcing by-products in the false ceiling and those in the hallways. The false ceiling was effective both in accumulating and containing smoke.

7.4.2.2 If an arcing fault occurs inside the metalclad, smoke will penetrate other compartments.

In general, it was observed that during any arcing fault inside the mock-up, but particularly for faults where the arcing was produced in or vented directly from the false ceiling, the building vent could be seen to "swing open" in response to the pressure wave produced by the arc.

7.5 Test Performance Comparisons

7.5.1 Smoke in the false ceiling remains in the false ceiling.

7.5.2 When smoke is generated relatively unenergetically, as with a smoke bomb or during a low level fault, it diffuses slowly through the structure. As is shown in Table IV, for example, smoke generated in the bus compartment reaches the breaker compartment and hallways.

7.5.3 Smoke generated inside a switchgear cell penetrates other cell compartments.

7.6 The Electrical Significance of PDD

Figure 7 presents the reductions in flashover voltage resulting from various degrees of carbon soot pollution (PDD) on insulating surfaces. To place the PDD observed during this test program into a practical perspective, the relationship between carbon soot pollution and reductions in flashover voltage of Figure 7 has been used to determine probable reductions in flashover voltage inside the metalclad switchgear breaker compartment resulting from the introduction of smoke. In Table IV, the test data for all tests where:

(i) smoke was generated for 1 minute where indicated,
(ii) ventilation fans were OFF at the start of the test,
(iii) the false ceiling vent was closed,
(iv) metalclad filters were not used (ie. 1200 A cell),

has been averaged to produce representative PDD levels (see Appendix C). The PDD so determined were converted to insulation strength reductions to illustrate the probable effect the pollution might have on the breaker insulation system.

TABLE V: The Electrical Significance of PDD

Arcing in:	Breaker Compartment Response	
	PDD ($\mu g/cm^2$) (avg.)	% Reduction in Flashover Voltage
Breaker	9.62	19.5
Bus	1.14*	7.5
Cable	0.04	<5.0

* : includes PDD from three phase arcing fault in bus compartment.

The following observations may be made:

7.6.1 A PDD less than 1 $\mu g/cm^2$ probably does not significantly compromise system insulation. In general, when smoke was generated in metalclad compartments furthest from the breaker, it resulted in insignificant insulation system compromises in the breaker compartment. However, when smoke was generated in the bus compartment (ie the middle compartment), there were significant insulation system compromises in the breaker compartment.

7.6.2 A PDD greater than 4 $\mu g/cm^2$ represents insulation reductions of about 10%. When smoke was generated in the breaker compartment, insulation system compromises of almost 20% resulted.

7.7 Smoke Particle Size

As shown in Table VI, the aerosols produced by smoke candles, the burning of epoxy resin insulation and XLPE insulation, and the single and three phase arcing tests were comparable in size. All particles produced during these tests were in the submicron range. It is worth noting that for the aerosols produced by any form of arcing, copper was a significant component. Since any aerosols less than about 2.5 microns in size can be easily respirated, breathing protection for workers in an area contaminated by the by-products of an arcing fault will have to be considered.

TABLE VI: Particle Size and Elemental Analysis of Aerosols Collected During Smoke Tests

Test Condition	Particle size (μm)	Elemental Constituents
Particulates from smoke candles.	<0.8	Carbon, Chlorine, Zinc, Sodium
Burning of epoxy insulation.	<0.2	Carbon, Silicone, Chlorine
Burning of XLPE.	<0.05	Carbon, Silicone, Chlorine Zinc, Sulphur
Single phase arc external to metalclad	<0.2	Carbon, Silicone, Calcium, Iron, Copper, Nickel
Three phase arc in Bus compartment.	<0.1	Carbon, Aluminum, Silicone Chlorine, Calcium, Iron, Titanium, Copper, Zinc

The size distributions of the particles resulting from a fault also has implications for selecting appropriate filter materials for those metalclad arrangements requiring increased convective cooling. The furnace-type filter employed in filtering the convective cooling air of the 3000 A metalclad switchgear was found to be less than 10% effective in removing the submicron smoke and fumes resulting from an arcing fault. Better filtering systems using more efficient materials should be considered in this application.

7.8 Pressure Rise

Figure 11 presents the pressure rise in the false ceiling in response to a three phase arcing fault (26 kA avg per phase) inside the bus compartment. The following observations may be made:

7.8.1 Peak pressure rise in the false ceiling reached 1.51 kPa (0.22 psi), with the pressure pulse lasting about 200 ms.

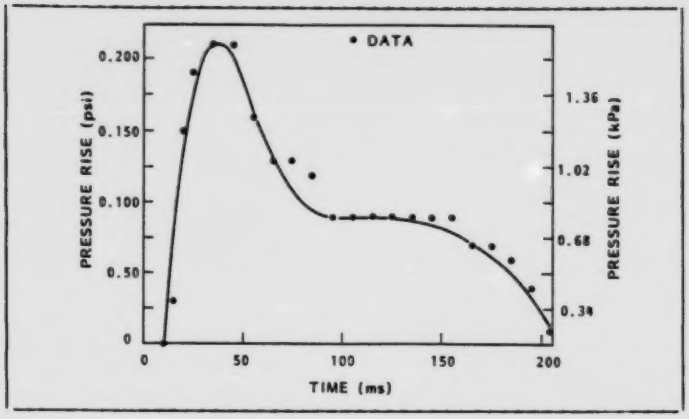


FIGURE 11:
False Ceiling Pressure Rise--26 kA Three Phase Arcing Fault

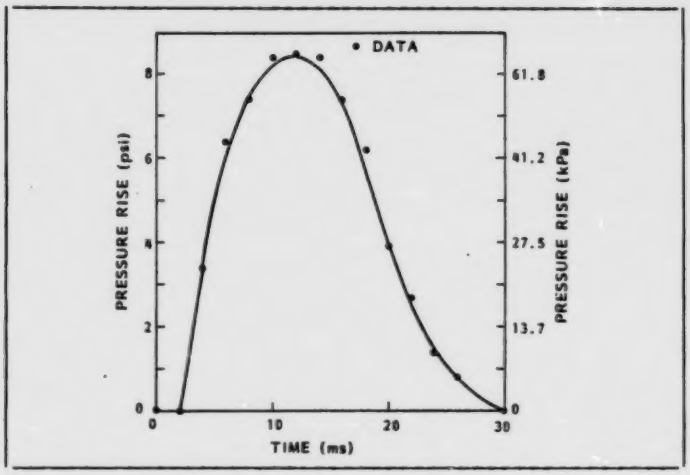


FIGURE 12:
Bus Compartment Pressure Rise--26 kA Three Phase Arcing Fault

7.8.2 A pressure rise inside the bus compartment of nearly 62.14 kPa (9 psig) and lasting for about 30 ms was recorded (see Figure 12).

A comparison between calculated and observed pressure rise was made using several algorithms based upon adiabatic system response to arc energy input/7,8,9/. As can be seen in Figure 13, reasonably good agreement between observed and calculated pressure rise is evident with some of the algorithms.

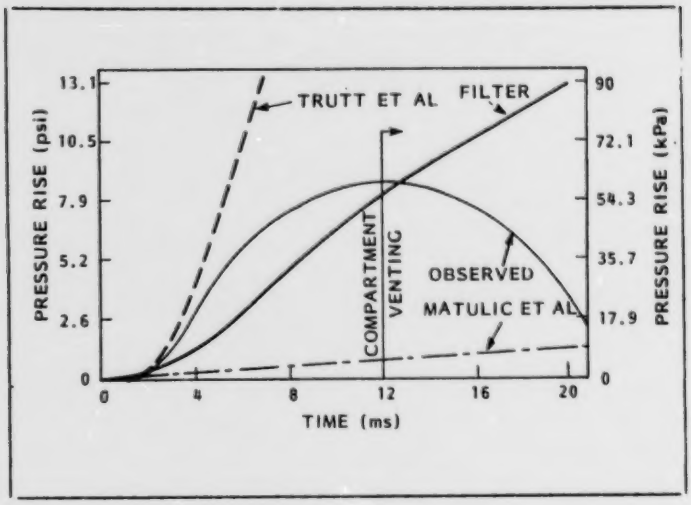


FIGURE 13:
Calculated and Observed Pressure Rises in Bus Compartment

One source of error between calculated and predicted pressure rise provides insight into the pitfalls of using theoretical techniques in assessing short term pressure response to arcing faults in this application. In previous cases where good agreement between calculated and observed pressure rise had been obtained/7/, the volume of the arcing chamber did not include internal structures. In this present case, the bus compartment includes a complex array of bus, as well as terminating and feedthrough bushings. It is likely that the arcing in this relatively cluttered environment initiated a system response which included the effects of the additional structures inside the compartment. In particular, it is probable that pressure build up did not occur uniformly throughout the volume in response to the interference from internal structures.

Several comments and observations can be made:

(i) The algorithm used by Matulic/9/ does not recognize the non-linear nature of the energy input into the system and attempts to determine pressure rise from a purely linear approximation based on the number of half cycles of fault current. This approach seriously underestimates system response.

(ii) The algorithm provided by Trutt et.al./8/ acknowledges the non-linear nature of the energy input. However, for times in excess of about 4 ms the difference between predicted and observed performance increases.

(iii) The algorithm used in previous Ontario Hydro tests/7/ tends to

underestimate pressure rise. Internal interfering structures inside the bus compartment are a likely cause.

For design purposes, with similar metalclad structures, the pressure rise calculated by algorithms provided by Trutt/8/ and Filter/7/ can be used as a guideline, recognizing that Filter's approach may underestimate the true response and Trutt's may overestimate it. In either case however, the durations of the pressure pulses resulting from venting of the arcing gases will limit the pressure rise in the metalclad to a pulse of about 30 ms duration and in the false ceiling to about 200 ms.

7.9 Wall Motion

During any arcing fault inside a closed structure, pressure rise will occur. One significant consequence of this pressure rise is that the structure walls will move or buckle slightly. In designing a full scale version of the ventilation system tested during this test program, information pertaining to the degree of buckling or movement of the walls in response to an internal arcing fault will be useful for building designers. In Table VII below the mock-up structure wall movement as a function of arcing fault current is presented for future design purposes.

TABLE VII: False Ceiling Wall & Floor Motion in Response to Arcing Faults

Fault Arc Location	Fault Arc Current (kA)	Motion (in mm) of:	
		False Ceiling Wall	False Ceiling Floor
False Ceiling	12	0.6	---
	24	2.0	1.3
	28	3.0	1.5
Bus Compartment	12	0.3	0.3
	26	0.7	0.6

7.10 Smoke Clearing Times

In Table VIII, the time it took for smoke to be cleared from the front hall and the false ceiling have been tabulated for several ventilation scenarios. The criteria used for assessing clearing times was that timing was started once smoke had completely filled the chambers, and/or once the fans had been manually triggered, and, timing was stopped once clear visibility from one end of the hall or chamber to the farthest end had been restored. The exception to this procedure was the case where the ventilation fans were running from the start of the test. In that circumstance, clearing times were determined using the start of the test as the starting point.

TABLE VIII: Front Hall and False Ceiling Smoke Clearing Times

VENTILATION SCENARIO	LOCATION	
	FRONT HALL Average Clearing Time (minutes)	FALSE CEILING Average Clearing Time (minutes)
Fans running at smoke initiation	2.54	5.88
Fans manually Triggered	2.01	----
Fans triggered by smoke detectors	2.70	6.20
Exhaust fan-ON Supply fan-OFF	----	6.10*
Supply fan-ON Exhaust fan-OFF	----	8.30*

*: Single readings, not averaged.

Several observations and comments can be made from the data in Table VIII:

7.10.1 Less than 45 seconds difference was evident, on average, between clearing times when the fans were triggered by hand and when they were triggered by the smoke detectors. This means that using the smoke detectors to trigger ventilation is viable and almost as efficient as observer triggering.

7.10.2 With the fans continually running, the shortest smoke clearing times are obtained. However, the difference between having the fans continually running and having them triggered by smoke detectors is, on average, less than half a minute in the total smoke clearing times. This marginal increase in smoke clearing efficacy may not be worth the costs and maintenance associated with having station ventilation fans continuously running.

7.10.3 When either supply or exhaust fans are used alone, in general, the ventilation system can be less effective in smoke clearing than when both fans are used together. When only the exhaust fan is used, ventilation system performance for removing air can approach that of the scenario with both fans running; however, for effective smoke removal from the hallways both supply and exhaust fans should be running. When only the supply fan is used, substantial smoke clearing performance degradation is evident.

7.11 Noise

In Table IX, noise readings over the audible frequency range taken in the structure hallways are presented. As is evident, even during relatively high current arcs, the noise levels recorded during the tests were within the limits of 135 dbA specified in The Ontario Hydro Corporate Safety Rules/10/. Workers exposed to noise in excess of 135 dbA are required to wear hearing protection.

TABLE IX: Audible Noise Recordings during Single Phase Arcing Faults in Bus Compartment

Test Current (kA)	Arc Duration (cycles)	Noise Reading (dbA) Front Hall	Rear Hall
12	12	117	121
25	12	122	125

Note: Sound level meter readings were obtained at ear height using two instruments, the General Radio 1988 Integrating Sound Level Meter, and the Larson Davis Sound Level Meter. Both instruments were calibrated prior to the tests.

8.0 OTHER SIMILAR TESTS

In 1986 Ontario Hydro representatives witnessed similar arc proof testing of a section of BBC metalclad switchgear under similar test conditions. In those tests, a three phase fault arc at 28 kA lasting 10 cycles was initiated inside the metalclad. That test resulted in heavy damage to the metalclad, with bent and deformed walls and buckled seams.

During the testing at Ontario Hydro, damages were incurred to the metalclad in that walls were deformed and four of the eight retaining bolts used to hold the steel barrier in place between the breaker cell and the bus compartment were sheared. However, unlike the BBC test results, none of the barriers between other compartments were blown away from their supporting frames.

After the dramatic results at the BBC test facility, BBC advised Ontario Hydro that additional bracing would be required to provide the arc-proofing necessary. As a result, prior to the Ontario Hydro tests, the walls and compartments of the test cell were strengthened.

As a result of the bracing and because, as is shown in Appendix D, 14% less energy was liberated inside the switchgear cell in the Ontario Hydro tests than had been liberated during the BBC tests, metalclad performance improvements were observed. Catastrophic switchgear failure did not occur.

9.0 CONCLUSIONS

9.1 Smoke Migration

1. The false ceiling is effective in containing smoke at any breaker operating temperature, no matter which ventilation scenario is used.

2. Triggering the ventilation fans with smoke detectors is as effective in controlling smoke as continuously running the fans. In particular, the status of the ventilation fans (ON/OFF) at fault initiation does not affect the amount of smoke retained inside the switchgear cells.

3. Metalclad sealing is effective in limiting smoke ingress into 1200 A switchgear cells. However, once smoke is inside a switchgear cell, it will penetrate adjacent cell compartments, the false ceiling and it may penetrate building hallways.

4. For switchgear rated at 3000 A, smoke from the hallways permeates the switchgear cells and is passed into the false ceiling.

5. Furnace type filters have no effect on smoke penetration into switchgear cells from the hallways. Filters are marginally effective in limiting smoke penetration into the cells from the false ceiling.

9.2 Smoke Detectors

The following conclusions pertaining to smoke detector performance during this series of tests can be drawn from the test results. It must be noted that, for the most part, the conclusions listed below represent detector performance with smoke generated by smoke candles. Detector performance may be slightly different with a different type of smoke.

1. In areas where high smoke densities are expected, there is very little difference in the mean annunciation time of photoelectric and ionizing type detectors.

2. In areas of relatively low smoke density, the annunciation times of the photoelectric detectors tended to be somewhat faster than those of the ionizing detectors.

3. In low smoke density locations, ionizing detectors failed to annunciate far more often than did photoelectric type detectors.

9.3 Smoke Clearing Times

1. Using the smoke detectors to trigger the smoke control ventilation is viable and almost as efficient as observer triggering.

2. Running the ventilation fans continually only results in marginal improvements in smoke clearing times over performance observed with smoke detector triggered ventilation.

3. Best smoke clearing performance, above or below the false ceiling, is obtained when both supply and exhaust ventilation fans are running simultaneously. Using either supply or exhaust fans alone may not be as efficient as using both systems together.

9.4 Audible Noise

Measurements of audible noise in the hallways during arcing faults inside the metalclad demonstrated that noise levels for which hearing protection is required are not likely to occur as a result of an arcing fault inside the metalclad switchgear.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

R. Filter
Engineer
Electrical Testing & Development Section
Electrical Research Department

T. Jarv
Scientist
Environmental Science Section
Chemical Research Department

RF:TJ:TMAC

REFERENCES

1. Filter, R., "Heat Run Tests at Charles TS", OHRD report #79-393-K, Sept. 12, 1979.

2. Armstrong, G.N., "Uprating The Ampacity of Wiltshire TS to 2850 Amps",OHRD report #80-217-K, June 3, 1980.

3. Filter, R., Jarv, T., "Application of the Fault Current Diverter (FCD) in the Transmission Station Environment", OHRD Report #87-310-K, February, 1988.

4. Jarv, T., "Smoke Penetration Studies at Overbrook TS, Ottawa, Ontario", OHRD report #87-215-K, August 25, 1987.

5. Oda, S.J., "Evaluation of Fire and Smoke detection Systems", OHRD Report #75-127-H, April 4, 1975.

6. Kawai, M, "Insulation For Power Frequency Voltage", Transmission Line Reference Book, 345 kV and Above, Chapter 10, pages 296-324.

7. Filter, R., "Short Circuit/Pressure relief Tests on A Canrep 4-kV Motor Terminal Box", OHRD Report #78-492-H, December 29, 1978.

8. Trutt, F.C., Robinson, J.W., Morley, L.A., "Arcing Phenomenon in Explosion-Proof Enclosures", IAS 1977 Annual, pages 1003-1009.

9. Matulic, R., Schaefer, W.J., Mara, E.G., "Design, Testing, and experience with 15 kV Enclosed Switchgear", IEEE PAS 96, No. 2, Mar/Apr 1977, pages 586-590.

10. The Ontario Hydro Corporate Safety Rules--1979, Sect. 331, subsect. 1C.

11. Greenwood, A., "Electrical Transients in Power Systems"; A Text, John Wiley & Sons Ltd. 1970.

APPENDICIES

APPENDIX A:TEST PROTOCOL

Acceptance Criteria

General:

The requirements for personnel safety and equipment protection in the following test procedure are very stringent and based on ideal situations. They may be relaxed or broadened, depending on the individual test results.

Personnel Safety

There shall be no amount of visible smoke or particles detected below the false ceiling within the first five minutes after the smoke releasing incident.

Equipment Protection

1. There shall be no amount of visible smoke or particles detected inside the cell at any time when smoke is generated outside the cell.

2. There shall be no significant amount of visible smoke or particles detected (a) in the adjacent compartments or (b) outside the cell below the false ceiling at any time when the smoke is generated inside the switchgear cell compartment.

3. In situations where personnel safety and equipment protection cannot be satisfied simultaneously, personnel safety takes precedent over equipment protection.

Test Protocol

A.1 Limited Ventilation

A.1.1 Supply and Exhaust Fans OFF

A.1.1.1 Generate smoke for two minutes to produce zero visibility at three locations simultaneously: Front Hall, Rear Hall, and False Ceiling.

A.1.1.2 Generate Smoke for one minute at three locations one at a time: Breaker Compartment, Bus Compartment, and Cable Compartment. Hinged flaps closed.

A.1.2 Repeat A.1.1.1 & A.1.1.2 with supply fans ON.

A.1.3 Repeat A.1.1.1 & A.1.1.2 with Exhaust fans ON.

A.2 Forced Ventilation: Supply and Exhaust Fans ON

A.2.1 Repeat A.1.1.1 & A.1.1.2. The supply and exhaust fans shall be turned on (a) before the smoke is generated, and (b) only after the first alarm from any smoke detector outside the switchgear cell is acknowledged. Waive (b) if outside smoke detectors do not pick up.

A.2.2 To simulate arcing, repeat A.2.1 with the blow-out vent open. Smoke is generated in False ceiling only for A.1.1.1. Do not repeat A.1.1.2.

A.3 Simulate 1200 A Cell Performance

A three phase 1200 A current is supplied to the circuit breaker to simulate a "hot" breaker condition. Monitor inside ambient air temperatures.

A.3.1 Repeat A.2.1 & A.2.2.

A.4 Simulate 3000 A Cell Performance

A.4.1 Repeat A.2.2. Louvres and/or openings shall be provided to simulate the "hot" breaker condition. First test with filters and then without filters.

A.4.2 Pressurize the breaker and feeder compartments and repeat A.2.2.1.

A.5 Arcing Faults

Provide a single phase arcing fault in the false ceiling to assess the response of the false ceiling and the structure to arcing faults. Re-

inforce the 1200 A test cell as instructed by BBC and provide a three phase arcing fault in the Bus compartment.

A.5.1 With no ventilation, initiate an arcing fault with limited current and duration to (i) calibrate pressure transducers, (ii) check roof and wall integrity. Increase arcing current and duration to determine system response to arcing.

A.5.2 With forced ventilation initiate an arcing fault of 25 kA, three phase, and of duration of 10 cycles.

APPENDIX B: LAY-OUT, FANS, DUCTING & COMMISSIONING

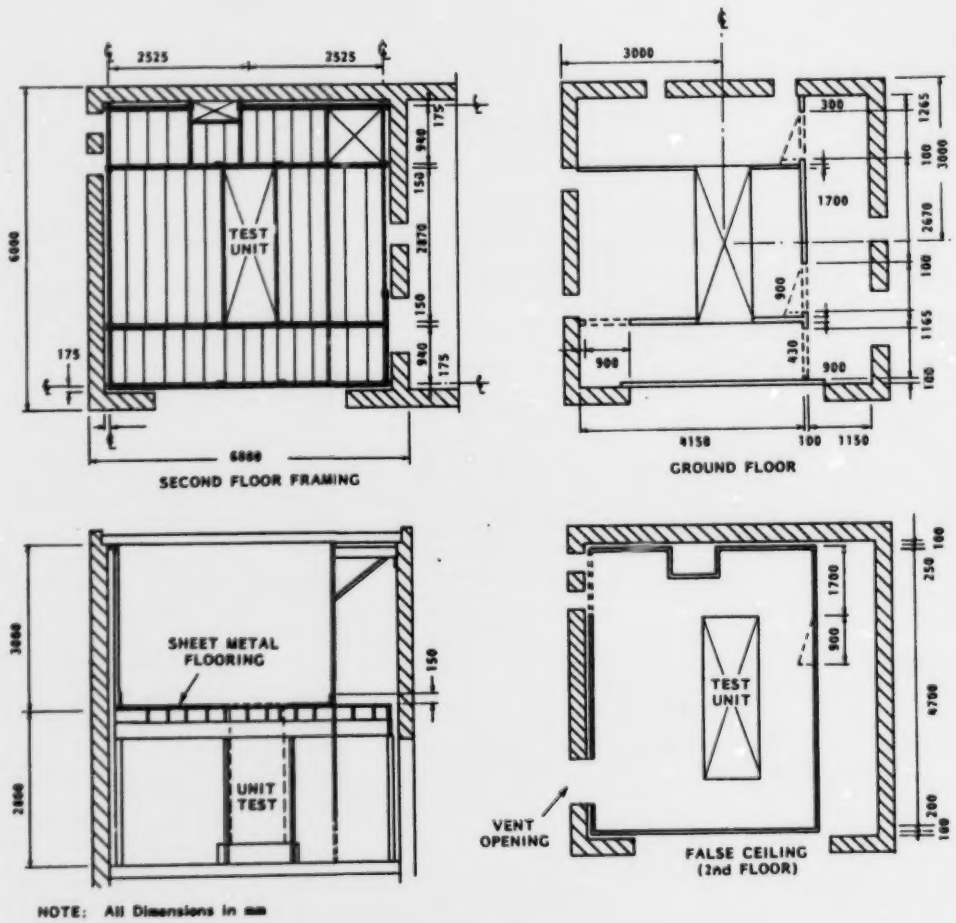


FIGURE B-1:
Lay-out Drawings of Test Set-up at Research

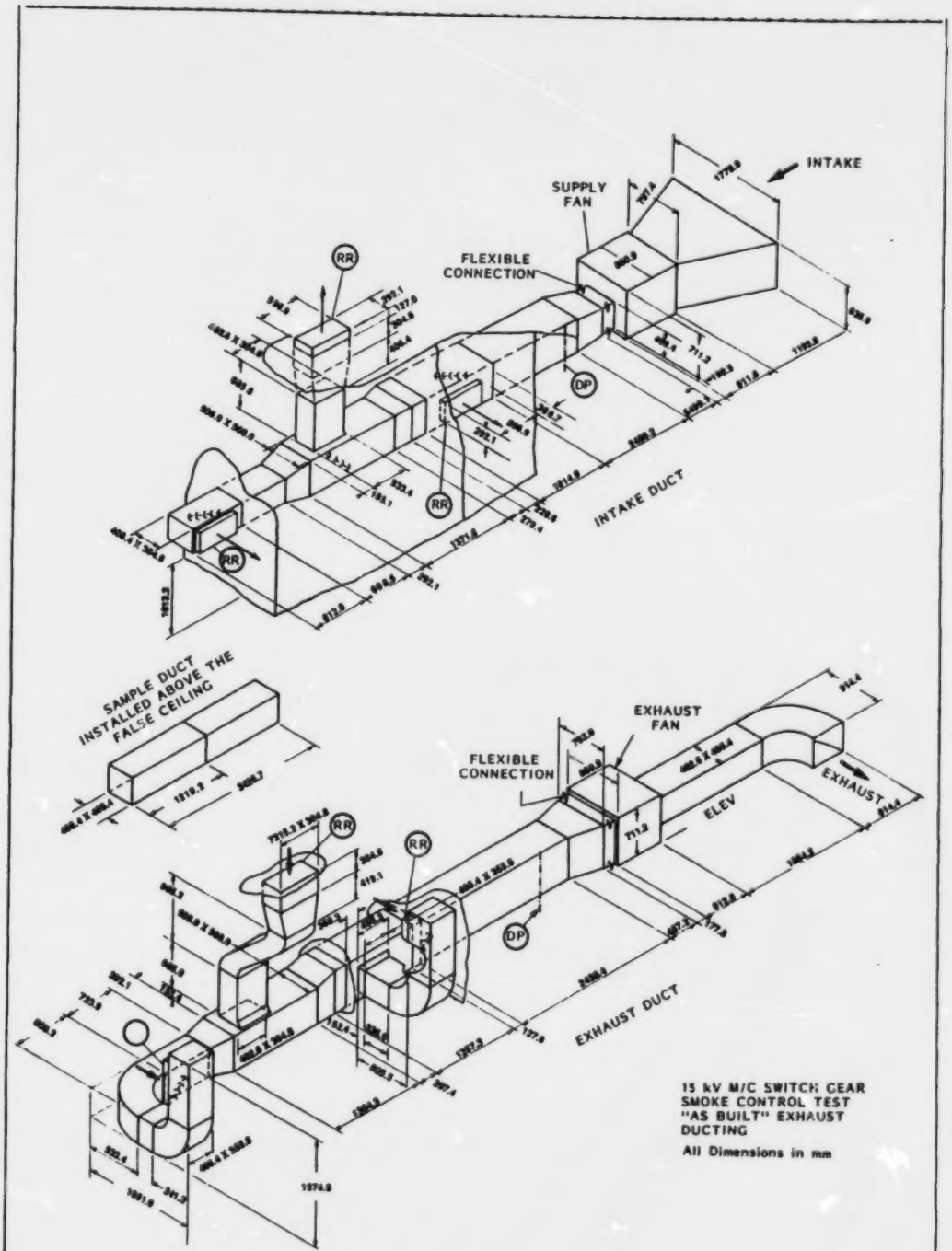


FIGURE B-2:
Ventilation System Ductwork

FILTER SECTION.

Widely used in conjunction with HE /G, COOLING and VENTILATING Systems.

An Economical, Quiet, Efficient solution for many Air Moving Requirements.

Sized with 7" - 9" - 10" - 12" - 15" Blowers.

offert en option.

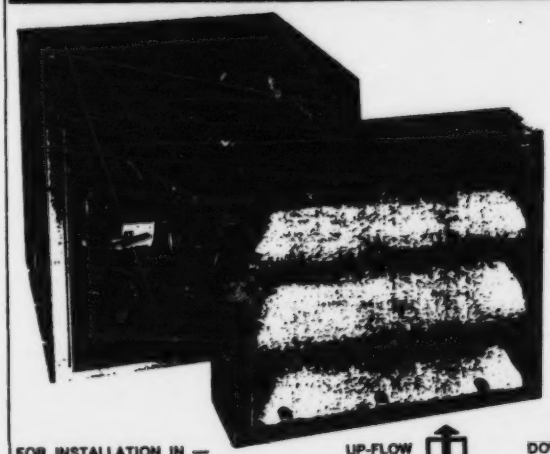
Largement utilisé s les systèmes DE CHAUFFAGE, DE CLIMATISATION et DE VENTILATION.

Une solution économique, silencieuse et efficace à de nombreux problèmes de ventilation.

Souffleurs de 7" - 9" - 10" - 12" - 15".

DELHI SOUFFLEURS et FILTRES pour CONDUITS DUCT BLOWERS - DUCT FILTERS

SERIE 200 SERIES



SINGLE or TWIN UNITS
INSULATED or NOT INSULATED

APPAREILS SIMPLES ou JUMELES
ISOLES ou NON ISOLES

FOR INSTALLATION IN — UP-FLOW
INSTALLATIONS DANS UN COURANT — ASCENDANT

DOWN-FLOW
DESCENDANT

HORIZONTAL
HORIZONTAL
POSITIONS

- Blower is equipped with Ball Bearings which have an operating temperature range of —65° to +250°F. (—54° to +121°C.).
- Blower is firmly mounted on 2 heavy steel reinforcing channels which also contain 9/16" holes necessary for hanging bolts when unit is suspended with over-head duct work.
- Blower is rubber mounted for quiet operation.
- Motor is securely fastened to blower with a hinge bolt for belt adjustment and allows the Duct Blower to be used in all 3 DISCHARGE POSITIONS, except 215.
- Models 215 and 215-2 duct blowers are equipped with motor mounting brackets for 2 HP on 215 and 3 HP on 215-2 Twin. Suitable for bottom and top horizontal positions only.
- EASILY SERVICED: Access panels on both sides allows easy servicing to blower and motor.
- Optional FILTER SECTION has drawer type filter rack allowing EASY MAINTENANCE. Filter Sections are shipped with 1" Throw-away Filter Media.
- TWIN DUCT BLOWERS are tied together with angle iron runners (see drawing on back page). The two blowers are on a common shaft and driven from one end.
- If Duct Filter is required for Twin Duct Blower order two single duct filters.
- Replacement parts are carried on Delhi Blowers in all principal Canadian Cities. No delay for parts when you specify Delhi Air Moving Products.

- Roulements à billes standard. Températures de fonctionnement: —65° à +250°F. (—54° à +121°C.).
- Le souffleur est solidement fixé à 2 fers en U d'acier qui possèdent des trous de 9/16" pour les boulons requis lorsque l'appareil est installé avec des gaines suspendues.
- L'appareil est monté sur caoutchouc pour un fonctionnement silencieux.
- Le moteur est attaché solidement au souffleur au moyen d'un pivot de charnière pour le réglage de la courroie, et il permet l'installation du souffleur dans l'une ou l'autre des 3 POSITIONS DE DECHARGE (sauf le 215).
- Le modèle 215 est muni d'une plate-forme pour moteur de 2 HP, et de 3 HP pour le modèle 215-2; ils ne s'installent qu'avec la partie inférieure et supérieure en position horizontale seulement.
- ENTRETIEN FACILE grâce aux panneaux donnant accès au moteur et au souffleur des deux côtés.
- LA CELLULE à FILTRE, offerte en option, possède un tiroir qui FACILITE LE REMPLACEMENT des filtres. La cellule est expédiée avec un filtre de 1" du type à jeter après usage.
- LES SOUFFLEURS JUMELES sont reliés par des fers angle (voyez le dessin à l'endos); ils ont un arbre commun et un moteur à un bout.
- Si un filtre est requis pour les souffleurs jumelés, commandez deux cellules simples.
- Les pièces de rechange sont disponibles dans toutes les principales villes du Canada; aucun délai si vous spécifiez les produits Delhi.

ANOTHER AIR MOVING PRODUCT BY

APPAREILS DE VENTILATION

DELHI INDUSTRIES LTD. LTEE

SERIE 200 SERIES

DONNEES TECHNIQUES — PERFORMANCE DATA

MODEL HP LIMIT / MODELE HP LIMITE	P.C.M. C.F.M.	Outlet Vel. Sortie	1/8" PS SP		1/4" PS SP		3/8" PS SP		1/2" PS SP		5/8" PS SP		3/4" PS SP		1" PS SP		1 1/4" PS SP		1 1/2" PS SP	
			TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP	TPM RPM	HP HP
TIP SPEED (FPM) 2.07 x RPM **207**	400	780	800	.03	770	.05	910	.07	1040	.10	1165	.13	.....	.....	.....	.....	.....	.....	.....	.....
	500	951	860	.05	810	.06	940	.09	1065	.12	1170	.15	.....	.....	.....	.....	.....	.....	.....	.....
	600	1140	730	.07	865	.09	990	.12	1100	.14	1200	.18	.....	.....	.....	.....	.....	.....	.....	.....
SINGLE ¼ HP SIMPLE / TWIN ½ HP JUMELE	700	1331	805	.09	935	.12	1045	.15	1145	.18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	800	1520	890	.13	1000	.16	1100	.19	1200	.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TIP SPEED (FPM) 2.59 x RPM **209**	600	713	450	.05	570	.07	680	.10	790	.13	870	.17	980	.22	1100	.30	.....	.....	.....	.....
	800	951	500	.08	610	.10	715	.14	805	.18	890	.21	965	.26	1100	.36	.....	.....	.....	.....
	1000	1189	570	.11	670	.15	760	.19	840	.24	915	.29	995	.33	1125	.43	.....	.....	.....	.....
SINGLE ½ HP SIMPLE / TWIN ¾ HP JUMELE	1200	1427	650	.19	735	.22	805	.27	890	.32	960	.37	1015	.42	1150	.53	.....	.....	.....	.....
	1400	1665	735	.28	800	.32	870	.37	940	.43	1005	.48	1070	.53	.....	.....	.....	.....	.....	.....
TIP SPEED (FPM) 2.95 x RPM **210**	800	771	430	.06	540	.08	640	.11	725	.15	805	.18	870	.22	1000	.31	1110	.40	.....	.....
	1000	964	470	.09	570	.12	660	.15	740	.19	825	.23	895	.27	1010	.36	1125	.45	.....	.....
	1200	1157	515	.13	610	.16	695	.19	770	.24	845	.29	910	.34	1035	.43	1140	.53	.....	.....
	1400	1351	570	.18	650	.22	730	.26	805	.31	870	.35	935	.40	1055	.52	1160	.62	.....	.....
SINGLE ¾ HP SIMPLE / TWIN 1 HP JUMELE	1600	1543	630	.25	705	.30	770	.34	840	.39	905	.45	970	.50	1080	.62	1185	.73	.....	.....
	1800	1736	690	.34	760	.39	825	.45	885	.50	945	.56	1000	.61	1105	.74	.....	.....	.....	.....
VITESSE DE POINTE (PPM) 3.37 x TPM **212**	1200	823	380	.09	470	.11	570	.17	660	.23	735	.29	800	.34	905	.47	1005	.59	1095	.70
	1400	960	405	.12	500	.16	580	.21	660	.27	735	.33	800	.39	920	.54	1020	.68	1110	.82
	1600	1097	440	.15	520	.20	600	.26	685	.31	740	.38	805	.45	920	.60	1030	.76	1125	.95
	1800	1235	470	.19	550	.25	620	.32	685	.37	750	.44	810	.52	925	.67	1040	.86	.....	.....
	2000	1372	505	.25	575	.31	650	.38	705	.44	760	.50	820	.58	935	.75	1040	.95	.....	.....
SINGLE 1 HP SIMPLE / TWIN 1½ HP JUMELE	2200	1509	550	.33	605	.39	670	.45	730	.52	785	.59	835	.66	940	.84	1045	1.05	.....	.....
	2600	1783	625	.49	675	.57	735	.65	785	.72	840	.82	880	.90	970	1.07	.....	.....	.....	.....
	3000	2058	705	.74	750	.81	800	.90	845	.99	900	1.11	940	1.19	.....	.....	.....	.....	.....	.....
VITESSE DE POINTE (PPM) 4.03 x TPM **215**	2000	974	335	.14	415	.21	480	.28	545	.36	600	.45	650	.54	750	.78	825	.95	895	1.15
	2400	1169	370	.22	440	.28	505	.37	560	.45	615	.55	665	.65	755	.79	840	1.11	915	1.35
	2800	1364	412	.34	475	.40	530	.48	585	.57	635	.67	680	.78	785	1.00	850	1.27	920	1.52
	3200	1559	455	.48	510	.55	565	.64	610	.73	660	.84	700	.94	780	1.18	855	1.42	930	1.72
	3600	1754	500	.65	550	.73	600	.83	645	.92	685	1.03	725	1.15	805	1.41	875	1.67	945	1.98
SINGLE 2 HP SIMPLE / TWIN 3 HP JUMELE	4000	1948	550	.87	585	.96	630	1.05	675	1.18	715	1.28	755	1.40	825	1.65	900	1.96	.....	.....
	4400	2143	595	1.14	630	1.23	670	1.33	710	1.45	750	1.57	785	1.70	855	1.98	.....	.....	.....	.....
	4800	2338	640	1.47	675	1.56	715	1.68	745	1.78	785	1.93	.....	.....	.....	.....	.....	.....	.....	.....

FOR HIGHER S.P. AND LARGER HP REFER 5000 SERIES — POUR DES PUISSANCES OU DES P.S. PLUS ELEVEES, VOYEZ LA SERIE 5000

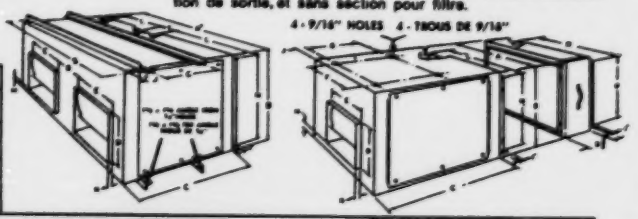
NOTE: The most efficient and quietest Blower or Exhauster is the one requiring the least H.P.

Ratings are for total horsepower. No allowance need be made for belt or bearing friction.

TWIN DUCT BLOWERS have double the above shown capacity for the same R.P.M. and S.P. and require double the horsepower, UP TO TWIN H.P. LIMIT.

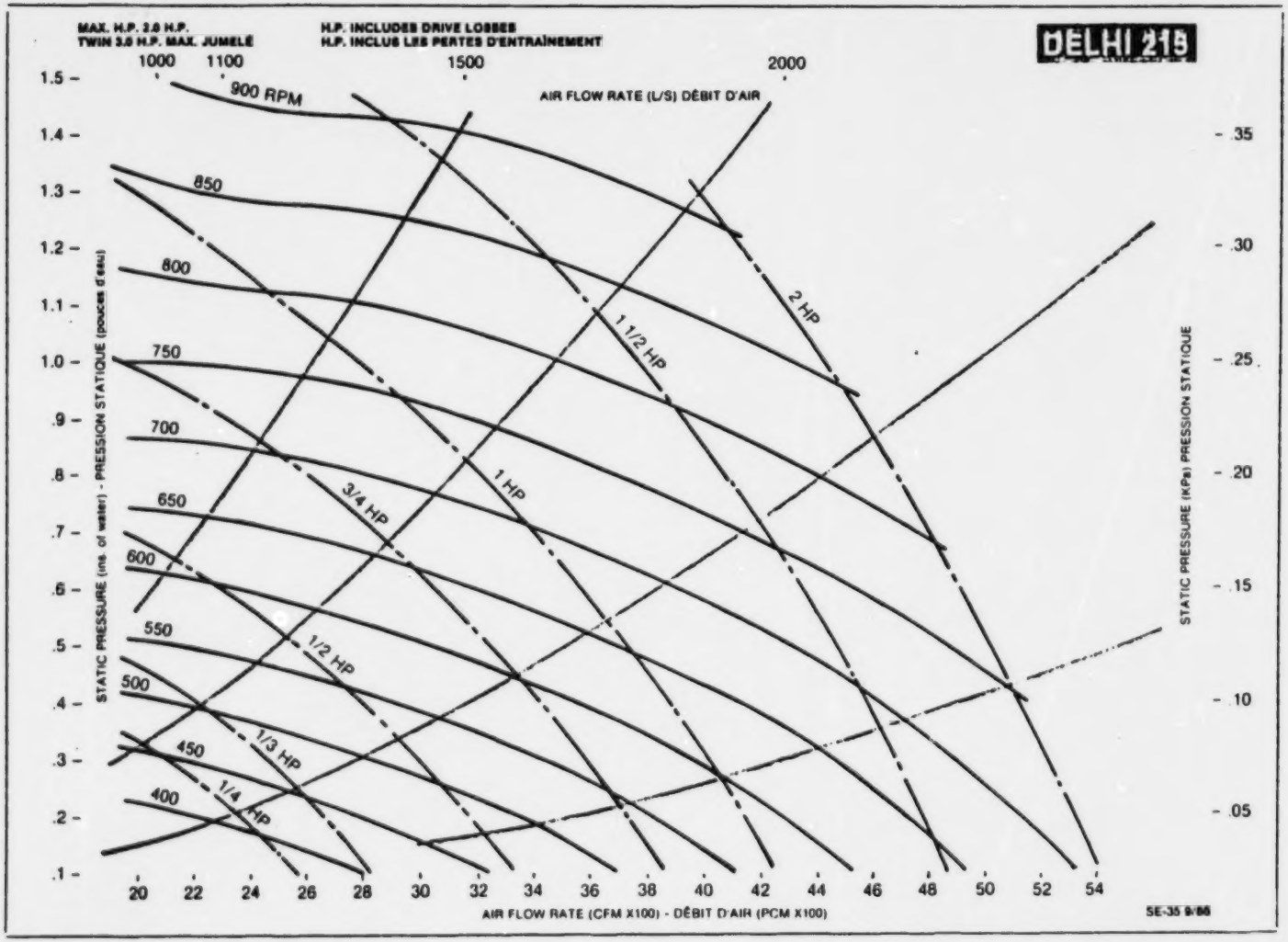
Tested by the Nozzle Chamber Method as described in A.M.C.A. Bulletin No. 210-74, Figure No. 15, without outlet duct, and without filter section.

NOTE: Le souffleur ou l'aspirateur le plus efficace et silencieux est celui requérant le plus petit moteur.
Puissance nominale totale. On n'a pas à tenir compte de la friction de la courroie et des roulements à billes.
LES SOUFFLEURS à double conduit ont un débit égal au double du débit ci-dessus pour le même TPM et une même PS et requièrent le double de HP, jusqu'à LA LIMITE DE L'UNITE JUMELEE.
L'appareil a subi avec succès les essais décrits dans le bulletin no. 210-74 de A.M.C.A., figure no. 15 sans canalisation de sortie, et sans section pour filtre.



DUCT FILTER - FILTRE pour CONDUIT					
MODELE MODEL	PO. CA. SQ. IN.	A	B	N	P
F207	531	17⅛	15⅛	16	13½
F209	683	21	18	19⅛	16⅛
F210	720	22¼	20	20⅛	16⅛
F212	900	27	23	25⅛	21⅛
F215	1460	33½	28	30⅛	25⅛

	DUCT BLOWER — SOUFFLEURS pour CONDUIT												TWIN - JUMELE			
	A	B	C	D	E	F	G	H	J	K	L	M	A2	R	S	T
207	16	15⅛	23	8⅛	9⅜	14½	9⅛	1¼	1¼	⅞	15⅛	13⅛	36	8 7/16	38⅛	2
209	21	18	23	10¼	11 3/16	17½	11⅛	1¼	1¼	⅞	19	16	42	9⅜	44⅛	2
210	22¼	20	24⅛	11⅛	13⅛	18⅛	13⅜	1¼	1¼	⅞	20¼	18	44½	9⅛	46⅛	2
212	27	23	27⅛	13⅜	15⅛	23½	16⅛	1¼	1¼	⅞	25	21	54	11⅛	56¼	2
215	33½	28	32	15⅛	18⅛	28	19½	2¼	1⅛	⅞	30½	25	67	14⅛	69¼	3


MAX. H.P. 2.0 H.P.
TWIN 3.0 H.P. MAX. JUMELÉ
H.P. INCLUDES DRIVE LOSSES
H.P. INCLUS LES PERTES D'ENTRAÎNEMENT
DELHI 215
AIR FLOW RATE (L/S) DÉBIT D'AIR
1000
1100
1500
2000
900 RPM
850
800
750
700
650
600
550
500
450
400
2 HP
1 1/2 HP
1 HP
3/4 HP
1/2 HP
1/3 HP
1/4 HP
STATIC PRESSURE (ins. of water) - PRESSION STATIQUE (pouces d'eau)
STATIC PRESSURE (kPa) PRESSION STATIQUE
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.35
.30
.25
.20
.15
.10
.05
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
AIR FLOW RATE (CFM X100) - DÉBIT D'AIR (PCM X100)
SE-35 9/86

Appendix B:Commissioning Tests

The following data was taken at the supply and exhaust ducting and fans to determine flow rates. Static pressures and velocities have been recorded downstream on the supply fan and upstream of the the exhaust fan on a plane near each fan under the conditions indicated in the tables. Each square in the tables represents a discrete area of the duct.

Conclusions which can be drawn from the tables include:

C.3.1 Fans operate within system design limits.

C.3.2 Ducting performed within design limits.

C.3.3 Damper settings and performance was verified.

C.3.4 Indicated turning vane setting provide optimum air flow.

SUPPLY DUCT READINGS
Air Flow Pilot Tube Measurements

Objective: Confirm fan performance and determine optimum plant settings.

Conditions: Cross-section plane of measurement at supply fan output.
: Both fans on; dampers fully open.
: V_p/S_p shown at each point; (in. of water).
: Temperature = -7.5 degrees Celsius.

Note: upper number in table is velocity pressure; lower number is static pressure.

0.07 0.10	0.08 0.10	0.08 0.09	0.10 0.09	0.10 0.09	0.12 0.10
0.08 0.10	0.09 0.09	0.10 0.08	0.12 0.08	0.11 0.09	0.15 0.09
0.11 0.10	0.11 0.09	0.13 0.08	0.13 0.08	0.18 0.08	0.27 0.08
0.20 0.10	0.15 0.08	0.13 0.08	0.15 0.08	0.22 0.08	0.32 0.08
0.10 0.10	0.13 0.08	0.10 0.08	0.20 0.08	0.20 0.08	0.30 0.09

SUPPLY DUCT READINGS
Air Flow Pilot Tube Measurements

Objective: Confirm fan performance and determine optimum plant settings.

Conditions: Cross-section plane of measurement at supply fan output.
: Exhaust fans off; dampers fully open.
: V_p/S_p shown at each point; (in. of water).
: Temperature = -7.5 degrees Celsius.

Note:upper number in table is velocity pressure; lower number is static pressure.

0.05 0.19	0.05 0.19	0.05 0.17	0.09 0.16	0.03 0.18	0.10 0.19
0.05 0.19	0.05 0.18	0.05 0.16	0.09 0.16	0.10 0.17	0.12 0.19
0.11 0.17	0.11 0.17	0.10 0.17	0.11 0.16	0.15 0.17	0.22 0.17
0.15 0.18	0.15 0.16	0.11 0.17	0.13 0.16	0.16 0.18	0.30 0.17
0.15 0.19	0.12 0.18	0.10 0.17	0.15 0.16	0.13 0.18	0.30 0.16

EXHAUST DUCT READINGS
Air Flow Pilot Tube Measurements

Objective: Confirm fan performance and determine optimum plant settings.

Conditions: Measurement point upstresm of exhaust fan.
: Both fans on; dampers fully open.
: V_p/S_p shown at each point; (in. of water).
: Temperature = -7.5 degrees Celsius.
: Inside duct temperature = 8 degrees Celsius

Note:upper number in table is velocity pressure; lower number is static pressure.

0.15 0.28	0.16 0.30	0.17 0.30	0.17 0.29	0.13 0.29	---- ----
0.16 0.28	0.15 0.30	0.16 0.30	0.16 0.30	0.15 0.30	---- ----
0.16 0.30	0.16 0.30	0.16 0.30	0.15 0.30	0.14 0.30	---- ----
0.15 0.28	0.15 0.30	0.10 0.30	0.10 0.32	0.10 0.32	---- ----
0.18 0.28	0.15 0.30	0.04 0.30	0.04 0.30	0.05 0.30	---- ----
0.12 0.28	0.10 0.29	0.05 0.30	0.03 0.30	0.02 0.30	---- ----

EXHAUST DUCT READINGS
Air Flow Pilot Tube Measurements

Objective: Confirm fan performance and determine optimum plant settings.

Conditions: Measurement point upstream of exhaust fan.
: Exhaust fan on, supply fan off; dampers fully open.
: V_p/S_p shown at each point; (in. of water).
: Temperature = -7.5 degrees Celsius.
: Inside duct temperature = 7 degrees Celsius

Note:upper number in table is velocity pressure; lower number is static pressure.

0.10 0.31	0.12 0.33	0.15 0.33	0.15 0.32	0.13 0.31	---- ----
0.11 0.22	0.11 0.33	0.13 0.33	0.12 0.33	0.11 0.32	---- ----
0.13 0.32	0.13 0.33	0.13 0.34	0.13 0.34	0.11 0.34	---- ----
0.12 0.32	0.12 0.34	0.09 0.34	0.10 0.34	0.09 0.32	---- ----
0.13 0.32	0.13 0.33	0.04 0.34	0.04 0.33	0.05 0.32	---- ----
0.10 0.33	0.10 0.33	0.04 0.34	0.02 0.32	0.02 0.32	---- ----

EXHAUST DUCT READINGS

Air Flow Pilot Tube Measurements

Objective: Confirm fan performance and determine optimum plant settings.

Conditions: Measurement point upstream of exhaust fan.
: Supply fan on, exhaust fan off; dampers fully open.
: V_p/S_p shown at each point; (in. of water).
: Temperature = 0 degrees Celsius.

Note: upper number in table is velocity pressure; lower number is static pressure.

0.03 0.20	0.04 0.20	0.05 0.18	0.05 0.17	0.05 0.18	0.08 0.20
0.05 0.18	0.07 0.20	0.08 0.18	0.08 0.20	0.08 0.20	0.11 0.20
0.11 0.17	0.11 0.18	0.08 0.18	0.11 0.18	0.11 0.20	0.18 0.20
0.13 0.20	0.11 0.20	0.11 0.18	0.15 0.18	0.18 0.18	0.22 0.18
0.10 0.18	0.11 0.18	0.11 0.18	0.15 0.18	0.15 0.18	0.23 0.18
0.10 0.33	0.10 0.33	0.04 0.34	0.02 0.32	0.02 0.32	---- ----

APPENDIX C: TABLE OF TEST RESULTS

APPEAR AT END OF DOCUMENT

APPENDIX D

Energy Considerations

Appendix D: Energy Considerations

SYMBOLS

$e_i(t)$ = energy input in joules

$i_a(t)$ = fault current in amperes

$P(t)$ = total arc power in watts

$V_a(t)$ = arc voltage in volts

ω = 377

t = time in seconds

D = air density in g/liter at STP

m = air mass in enclosure in grams

p = pressure rise

S_h = specific heat of air

T = temperature in Kelvin

l = arc length (m)

V_b = container volume (m^3)

Arc Energies

In order to compare test results from two different tests carried out at different times and at different test facilities, it is necessary to determine the relative arc energy input into each system and to base comparisons of observed performance on the available fault arc energy. Table D-I below lists the important characteristics of BBC and Ontario Hydro test set-ups.

TABLE D-I: BBC and Ontario Hydro Circuit Parameters

Circuit Parameter	From BBC Data (or estimated)	From Ontario Hydro Data
Phase Current (kA rms)	27	26 (avg)
First Peak (kA)	60	44.3
I(peak)/I(rms)	1.55	1.36*
X/R	15	3 (approx.)
Power Factor (%)	7	32
Closing Angle (rad)	0.8	0.26

* obtained using the offset phase only.

The electrical energy input to the arc inside the metalclad cell is the vector sum of the input electrical energies of each of the three phases involved in the fault. In general, input electrical energy is given by:

$$E_{in}(t) = \int P_T(t)dt$$

where $P_T(t) = P_{red}(t) + P_{white}(t) + P_{blue}(t)$
$= V_{red}(t)I_{red}(t) + V_{white}(t)I_{white}(t) + V_{blue}(t)I_{blue}(t)$

For the BBC test data and using the analytical approach suggested by Greenwood/11/, red phase current can be expressed as:

$$I_{red}(t) = I_A(\sin(\omega t + (0.8-1.5)) - \sin(0.8-1.5)e^{-25.16t})$$

$$= I_A(\sin(\omega t - 0.7) + 0.64e^{-25.16t})$$

including the effects of closing angle and power factor.

In an arcing fault, the arc voltage is in phase with the arc current (ie, the arc is a predominantly resistive impedance), and has been shown /7/ to be sufficiently accurately expressed as,

$$V_{red}(t) = \frac{4V_A}{\pi}\sin(\omega t - 0.7)$$

So that the arc power, normalized with peak voltage and current, can be expressed as

$$\frac{P_{red}(t)}{V_A I_A} = 0.74\sin^2 \omega t - 1.24\sin \omega t\cos \omega t + 0.52\cos^2 \omega t + e^{-25.16t}(0.62\sin \omega t - 0.52\cos \omega t)$$

Similarly, and bearing in mind that phase current and voltage waveforms are shifted 120 and 240 degrees from the referenced red phase, the normalized power for the white and blue phases is

$$\frac{P_{white}(t)}{V_A I_A} = 0.04\cos^2 \omega t + 0.46\sin \omega t\cos \omega t + 1.22\cos^2 \omega t - e^{-25.16t}(0.23\sin \omega t + 1.22\cos \omega t)$$

$$\frac{P_{blue}(t)}{V_A I_A} = 1.12\sin^2 \omega t + 0.81\sin \omega t\cos \omega t + 0.12\cos^2 \omega t - e^{-25.16t}(0.41\sin \omega t + 0.15\cos \omega t)$$

Note that the arc peak current and voltage, I_A and V_A, are assumed to be identical on each phase, ie, this analysis assumes a balanced fault.

The total input power is given by the sum of the phase powers as follows:

$$P_T(t) = V_A I_A(1.88 + 1.89e^{-25.16t}\cos \omega t)$$

so that the total input energy is given by:

$$E_I(t) = (2.87 \times 10^7)t + e^{-25.16t}((5.05 \times 10^3)\cos \omega t - (7.6 \times 10^4)\sin \omega t) - 5.05 \times 10^3$$

where $V_A = 400$ volts
$I_A = 38.1 \times 10^3$ amps

Results from Ontario Hydro Research Division tests can be treated in a similar way to produce a total input energy of

$$E_I(t) = (2.87 \times 10^7)t + e^{-126t}((2.29 \times 10^3)\cos \omega t - (6.86 \times 10^4)\sin \omega t) - 2.29 \times 10^3$$

Inspection of the energy input equations suggests several things about the nature of the energy being fed into the arc. On average, three phase energy input into the arc increases linearly. This increasing total arc energy input is affected, during the first few milliseconds, by the exponential/sinusoidal term, the effect of which decreases rapidly with time. During the first few milliseconds, there are decaying sinusoidal oscillations around the mean arc energy, the rate of decay, and the amplitude of the oscillations being dependent on circuit and test parameters.

Figure D-1 provides a comparison, over the time during which pressure build-up was observed to occur in the switchgear prior to venting, of the total electrical energy input to the system from the BBC tests and the Ontario Hydro tests.

From Figure D-1 several observations may be made:

D.1 For the first 8 ms, the energy input into the fault was virtually the same for both Ontario Hydro and the BBC tests.

D.2 After about 8 ms, the BBC tests delivered more energy than did the Ontario Hydro tests. This is due to the differences in the circuit parameters between the two test set-ups. By the time venting was observed to have occurred, at about 10-12 ms, the Ontario Hydro tests provided about 86% of the arc energy as the BBC tests.

Over the long term, all oscillations die out and the energy input by both tests is, by the end of the test, virtually the same. However, during the critical time when internal pressure builds up as a prelude to top venting, the BBC tests provided about 14% more energy than the corresponding Ontario Hydro tests.

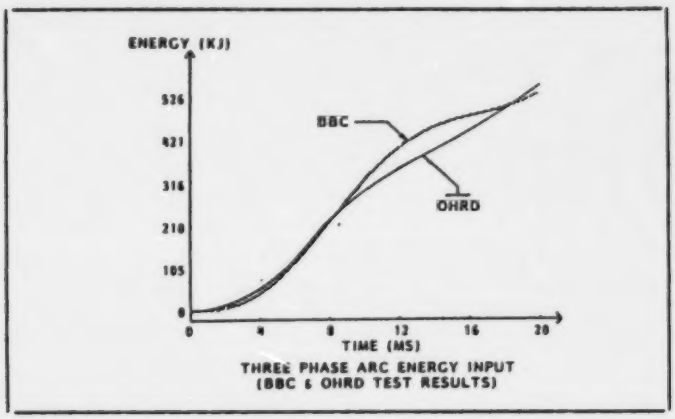


FIGURE D-1

Pressure Rises

An approach to determining the pressure rise in a small volume during an arcing fault was developed in /7/. In essence, this approach entailed the calculation of the system total input energy and then, by applying

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

where $P_2 = P_1 + P$ and P and T are pressure and temperature rises
$T_2 = T_1 + T$

so that

$$P = (P_1/T_1)T$$

But T is determined by the total input heat energy, ie

$$T = E_i/mS_h \qquad \text{and } m = V_b D$$

so that

$$P = (P_1/T_1)(E_i/(V_b\ D\ S_h))$$

where $E_1(t) = (2.87 \times 10^7)t + e^{-126t}((2.29 \times 10^3)\cos \omega t - (6.86 \times 10^4)\sin \omega t) - 2.29 \times 10^3$

and all other parameters have been previously defined.

Figure D-2 is a plot of the above, along with the actual values of pressure rises measured during the tests. As can be seen, reasonably close agreement between predicted and observed pressure rises is evident. Differences between predicted and observed results is due to inaccuracies in the chamber volume and interference introduced by the presence of bus structures and their associated bushings. The above analysis does not take pressure waves into account. In addition, some of the differences between predicted and observed performance may be due to the placement of the pressure transducer during the tests.

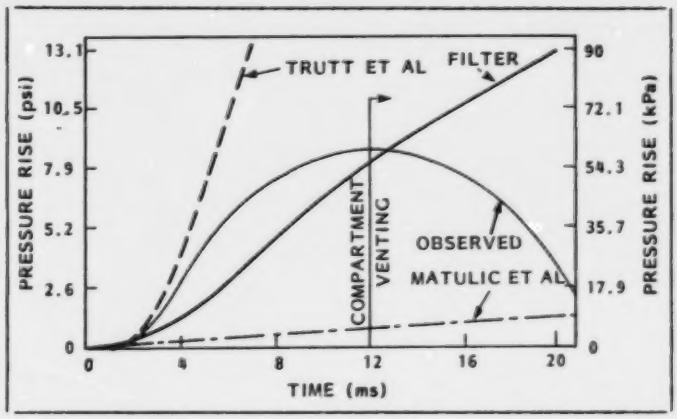


FIGURE D-2

In this test, the pressure transducer was mounted relatively close to the arc in a bottom corner of the bus compartment. This location is vulnerable to transient pressure rises during the arcing as a result of plumes and interference with bus structures. The pressure transducer in this location would not accurately measure average pressure rises inside the Bus compartment, but rather, ambient pressure rises PLUS the transient pressures due to plume concentration and reflections.

Metalclad Structure Ventilation Tests

TEST SEQ.	TEST CONDITIONS: TEST PLAN NUMBER.	CURRENT	SMOKE CANDLES: LOCATION	SMOKE CANDLES: DUR. min.	FANS: EXH	FANS: SUP	BLDG VENT	METAL CLAD FLTRS	OUT-SIDE AMB. (C)	FRONT HALL: AIR. TEMP (C)	FRONT HALL: DETECTORS: PH (min)	FRONT HALL: DETECTORS: ION (min)	FRONT HALL: PDD (ug/sq cm)	REAR HALL: AIR. TEMP (C)	REAR HALL: DETECTORS: PH (min)	REAR HALL: DETECTORS: ION (min)	REAR HALL: PDD (ug/sq cm)	FALSE CEILING: AIR. TEMP (C)	FALSE CEILING: DETECTORS: PH (min)	FALSE CEILING: DETECTORS: ION (min)	FALSE CEILING: PDD (ug/sq cm)	BREAKER: AIR. TEMP (C)	BREAKER: BUS TEMP (C)	BREAKER: DETECTORS: PH (min)	BREAKER: DETECTORS: ION (min)	BREAKER: MSDD (ug/sq cm)	BUS: AIR. TEMP (C)	BUS: BUS TEMP (C)	BUS: DETECTORS: PH (min)	BUS: DETECTORS: ION (min)	BUS: PDD (ug/sq cm)	CABLE: AIR. TEMP (C)	CABLE: DETECTORS: PH (min)	CABLE: DETECTORS: ION (min)	CABLE: PDD (ug/sq cm)	PART. SIZE MON: LOC.	PART. SIZE MON: SAT. TIME (MIN)	COMMENTS
1	A.1.1.1	0	RH,FC	2	OFF	OFF	CLSD	note (2)	N/A	6	2.93	4.59	0.52	10	1.41	1.50	6.62	11	1.86	2.32	4.23	17	-	-	-	0.03	16	-	2.81	-	1.96	14	-	-	0.00	BRKR	N/A	---
2	A.1.1.1	0	RH,FH	2	OFF	OFF	CLSD		0	9	-	1.23	9.94	13	1.88	2.15	10.39	9	3.02	5.48	0.20	15	-	1.32	-	0.30	15	-	-	-	0.06	17	-	-	0.07	BRKR	1.00	---
3	A.1.1.1	0	FH	2	OFF	OFF	CLSD		4	13	1.29	1.22	N/A	N/A	0.80	-	N/A	15	2.18	-	N/A	17	-	-	-	N/A	19	-	3.61	-	N/A	22	-	-	N/A	BUS	--	Particle size monitor did not saturate but showed an increase in smoke concentration at 3 minutes.
4	A.1.1.1	0	BRKR	1	OFF	OFF	CLSD		2	4	-	-	0.07	5	-	-	0.05	9	3.32	-	0.08	8	-	-	0.00	10.74	14	-	-	-	0.27	13	-	-	0.06	BUS	0.67	Slight leaks into FH & FC from BRKR compartment
5	A.1.1.2	0	BUS	1	OFF	OFF	CLSD		0	10	-	-	0.19	8	-	-	0.43	10	-	-	0 06	13	-	-	-	0.29	12	-	0.00	0.00	5.08	13	-	-	3.73	CABLE	1.50	Hinges of BUS comp. flaps leaked into FC. Smoke in CABLE compartment.
6	A.1.1.2	0	CABLE	1	OFF	OFF	CLSD		2	6	-	-	0.36	8	2.35	-	0.57	10	-	-	0.07	9	-	-	-	0.02	11	-	1.76	-	3.83	12	0.00	0.00	3.23	BUS	N/A	---
7	A.1.1.2 (see note 1)	0	CABLE	1	OFF	OFF	CLSD		2	6	-	-	0.10	8	0.55	-	0.17	10	-	-	0.06	9	-	-	-	0.05	11	-	0.64	1.30	2.08	12	0.00	0.00	8.71	BUS	0.50	Bus compartment flap hinges leaked into FC. Little or no smoke in BRKR compartment.
8	A.1.1.2	0	BUS	1	OFF	OFF	CLSD		2	6	-	-	0.15	7	-	-	0.26	10	-	-	0.36	10	-	-	-	0.14	13	-	0.45	0.26	5.20	14	3.14	3.26	2.02	BRKR	2.25	Smoke from flap hinges into FC.
9	MIS-FIRE	0	BUS	1	OFF	ON	CLSD		3	9	N/A	N/A	N/A	14	N/A	N/A	N/A	12	N/A	N/A	N/A	18	-	N/A	N/A	N/A	25	-	N/A	N/A	N/A	17	N/A	N/A	N/A	BRKR	1.33	Same as above.
10	A.1.2-A.1.1.2	0	BUS	1	OFF	ON	CLSD		3	4	-	-	0.31	6	-	-	0.17	9	2.11	-	0.31	9	-	-	-	0.24	15	-	0.40	0.22	2.35	13	1.32	2.16	4.87	BRKR	1.00	Smoke leaked into CABLE compartment through seal
11	A.1.3-A.1.1.2	0	BUS	1	ON	OFF	CLSD		6	12	-	-	0.38	13	-	-	0.13	11	1.01	-	0.18	13	-	2.09	-	0.69	13	-	0.28	0.00	N/A	15	1.13	0.86	4.84	BRKR	1.83	Smoke into FC through hinges on top flaps. Smoke penetrated into BRKR compartment.
12	A.1.2-A.1.1.2	0	CABLE	1	OFF	ON	CLSD		8	6	-	-	0.43	8	0.35	-	0.19	11	0.85	-	0.20	11	-	-	-	0.23	11	-	3.05	-	1.73	13	3.15	0.26	10.73	BRKR	--	No smoke in BRKR compartment. Smoke leaked into RH through panel seams on CABLE compartment.
13	A.1.3-A.1.1.2	0	CABLE	1	ON	OFF	CLSD		8	8	-	-	0.23	10	-	-	0.69	10	1.07	-	0.17	11	-	3.96	-	0.14	11	-	1.36	3.94	2.53	12	0.23	0.35	6.83	BRKR	1.67	Some smoke leaked into BRKR compartment. Smoke leaked into FC through flap hinges.
14	A.1.2-A.1.1.2	0	BRKR	1	OFF	ON	CLSD		8	10	-	-	0.36	12	-	-	0.43	15	2.51	-	0.69	17	-	0.19	0.08	9.88	17	-	0.91	-	0.96	18	-	-	0.32	BUS	1.83	Smoke leaked into FC from top flap hinges.
15	A.1.3-A.1.1.2	0	BRKR	1	ON	OFF	CLSD		6	7	N/A	N/A	0.16	9	N/A	N/A	0.16	11	N/A	N/A	0.11	15	-	N/A	N/A	11.75	16	-	N/A	N/A	0.41	15	N/A	N/A	0.17	BUS	1.83	Top flap hinges sealed.
16	A.1.3-A.1.1.2	0	BRKR	1	ON	OFF	CLSD		6	8	1.05	-	0.01	9	-	-	0.02	11	-	-	0.01	13	-	0.42	0.42	8.09	14	-	2.76	-	1.27	14	3.47	0.52	0.25	BUS	1.92	Smoke leaked into FH through BPKR front door.
17	A.1.2-A.1.1.1	0	FH,RH,FC	2	OFF	ON	CLSD		4	5	1.11	1.17	0.33	8	0.09	0.09	0.56	12	0.77	0.69	3.00	16	-	-	-	0.02	17	-	-	-	N/A	17	-	-	N/A	BUS	3.50	FH cleared in about 2 minutes.
18	A.1.3-A.1.1.1	0	FH,RH,FC	2	ON	OFF	CLSD		-6	-4	0.73	0.73	3.28	0	0.88	0.86	3.37	9	0.28	0.48	1.73	15	-	2.95	-	0.06	16	-	-	-	0.00	16	-	-	0.06	BUS	--	FC cleared in about 5 minutes. FH cleared in about 6.5 minutes.
19	A.2.1-A.1.1.1	0	FH, RH FC	1 2	ON	ON	CLSD		-6	-2	0.11	0.23	0.39	2	1.11	1.21	0.36	11	0.33	0.45	2.18	16	-	-	-	0.01	16	-	-	-	0.06	16	-	-	0.08	BUS	--	FH cleared in 2.5 min. FC cleared in 4.5 min.
20	A.2.1-A.1.1.1	0	FH, FC RH	1 2	OFF "ON" on det.	OFF	CLSD		-5	18	0.68	0.69	0.25	20	0.72	0.66	1.86	12	0.86	0.89	1.63	14	-	-	-	0.05	14	-	-	-	0.01	14	-	-	0.01	BUS	1.83	---
21	A.2.2-A.1.1.1	0	FC	2	ON	ON	OPEN		-3	21	-	-	N/A	21	-	-	0.11	12	0.29	0.29	1.94	16	-	-	-	N/A	14	-	-	-	0.05	15	-	-	0.05	BUS	--	No smoke out bldg vent. All smoke out exhaust vent. FC cleared in about 4 minutes.
22	A.2.2-A.1.1.1	0	FC	2	see #20		OPEN		-2	11	-	-	0.03	13	-	-	0.13	9	1.31	1.40	1.17	8	-	-	-	N/A	11	-	-	-	0.02	11	-	-	0.02	BUS	--	With no fans, narrow plume from smoke candles to bldg vent. With fans, smoke mixed. FC cleared in about 4 minutes.
23	A.2.1-A.1.1.1	0	BRKR	1	ON	ON	CLSD		-7	-5	-	-	0.00	-2	-	-	0.00	9	-	-	0.00	12	-	0.00	0.28	4.76	15	-	2.18	3.60	2.72	13	2.63	3.24	1.32	BUS	0.75	No smoke in FH.
24	A.1.1-A.1.1.1	0	CABLE	1	ON	ON	CLSD		-11	-4	-	-	0.00	6	0.52	-	0.04	10	-	1.13	0.23	10	-	-	-	0.02	10	-	3.34	2.00	1.95	12	0.23	0.22	1.96	SIDE COMP	--	No smoke in FH.
25	A.2.1-A.1.1.1	0	BUS	1	ON	ON	CLSD		0	1	-	-	0.01	4	-	-	0.01	5	0.76	-	0.12	11	-	-	-	0.01	7	-	0.00	0.21	6.13	9	2.51	-	1.96	CABLE	0.67	Smoke poured out of top flap hinges.
26	A.3-A.2.1-A.1.1.2	1200	BRKR	1	ON	ON	CLSD		-1	2	-	-	0.03	10	-	-	0.12	14	-	-	0.07	25	55	0.43	0.43	9.91	33	38	N/A	2.00	4.18	31	N/A	2.21	1.83	CABLE	1.90	New Breaker compartment door. No smoke in FH.
27	A.3-A.2.1-A.1.1.2	1200	BUS	1	ON	ON	CLSD		-1	3	-	-	0.02	15	-	-	0.05	15	0.98	-	0.21	21	55	0.40	-	0.18	29	36	0.22	0.00	9.25	26	0.50	-	0.73	CABLE	--	Smoke poured out of BUS top flap hinges.
28	A.3-A.2.1-A.1.1.2	1200	CABLE	1	ON	ON	CLSD		1	6	-	-	0.04	26	0.55	-	0.09	16	1.03	-	0.15	20	51	-	-	0.03	26	33	1.48	2.20	6.83	28	N/A	0.00	11.68	N/A	N/A	Smoke poured out of CABLE top flap hinges.
29	A.3-A.2.1-A.1.1.2	1200	CABLE	1	see #20 never trnd on		CLSD		1	5	-	-	0.05	16	-	-	0.01	16	-	-	0.06	14	49	2.38	-	0.06	24	31	1.65	1.87	7.31	26	0.10	0.26	9.40	N/A	N/A	Rear door sealed.
30	A.3-A.2.1-A.1.1.2	1200	BUS	1	see #29		CLSD		1	9	-	-	0.05	18	-	-	0.02	14	-	-	0.06	19	50	0.68	1.11	2.60	26	31	0.21	0.00	2.65	25	0.60	0.35	1.27	N/A	N/A	----
31	A.3-A.2.1-A.1.1.2	1200	BUS	1	ON	OFF	CLSD		1	6	-	-	0.05	12	-	-	0.08	12	1.13	-	0.13	16	50	0.30	0.80	0.39	23	29	0.03	0.03	4.49	21	-	0.53	1.96	N/A	N/A	Smoke travelled along floor to exhaust vents.
32	A.3-A.2.1-A.1.1.1	1200	FH,RH,FC	3	ON	ON	CLSD		3	26	0.15	0.28	1.23	30	0.25	1.10	0.58	20	0.23	0.30	5.49	32	63	1.33	-	0.18	34	40	4.13	-	0.17	34	-	2.80	0.58	BUS	1.00	Smoke penetrated into H/C. Hallways cleared after 3.5 min.; FC cleared in 7.5 min.
33	A.3-A.2.1-A.1.1.1	1200	FH,FC	3	see #20		CLSD		3	11	1.10	1.09	2.89	18	1.14	-	0.14	17	0.96	1.17	4.41	25	51	2.06	-	0.19	31	35	3.48	-	0.14	31	N/A	-	0.43	BUS	3.00	----
34	A.3-A.2.2-A.1.1.1	1200	FC	3	ON	ON	OPEN		3	6	0.30	0.30	0.04	11	1.07	-	0.04	12	2.75	-	2.53	16	54	1.85	-	0.04	28	36	-	-	0.03	27	1.5	-	0.06	BUS	--	No smoke came out of bldg vent. No smoke in FH. Smoke in FC cleared in 7.5 min.
35	A.3-A.2.2-A.1.1.1	1200	FC	3	see #20		OPEN		7	21	-	-	0.05	30	-	-	0.06	9	0.45	0.41	3.12	25	55	-	-	0.00	31	38	-	-	0.05	29	-	-	0.02	BUS	--	No smoke came out of bldg vent. FC cleared after 4 minutes.

| | | |

38	A.4-A.2.1-A.1.1.1	3000	FH,RH,FC	3	ON	ON	CLSD	NONE	-1	11	0.31	0.38	1.36	9	0.31	0.32	0.29	15	0.60	0.60	5.48	31	65	0.50	0.55	1.04	39	46	1.50	2.70	0.85	37	1.65	1.35	1.20	BUS	0.75	FH cleared in 4.5 min.; FC cleared in 9 min.
39	A.4-A.2.1-A.1.1.1	3000	FH,RH,FC	3	see	#20	CLSD	NONE	1	21	0.43	0.43	1.52	13	0.56	0.53	0.35	18	0.75	0.78	6.30	34	66	0.71	0.70	1.45	41	46	1.50	2.91	0.94	39	1.48	2.08	1.31	BUS	0.83	FH cleared in 4.5 min.; FC cleared in 6 min.
40	A.4-A.2.1-A.1.1.1	3000	FH,RH,FC	3	see	#20	CLSD	YES	4	23	0.61	0.61	1.14	19	0.63	0.63	0.64	14	0.55	0.73	5.45	41	67	0.93	1.10	0.83	37	46	1.61	3.11	0.79	37	1.42	1.61	1.60	BUS	1.10	FH cleared in 4 min.; FC cleared in 6 min.
41	A.4-A.2.1-A.1.1.1	3000	FH,RH,FC	3	ON	ON	CLSD	YES	0	11	0.16	0.20	1.73	14	0.11	0.11	1.71	14	0.55	0.70	4.61	43	69	1.36	0.75	1.42	40	46	1.51	1.86	1.31	37	1.50	1.44	1.52	N/A	N/A	FH cleared in 3.5 min.; FC cleared in 8 min.
42	A.4-A.2.2-A.1.1.1	3000	FC	3	see	#20	OPEN	YES	-6	18	-	-	0.06	17	-	-	0.18	13	0.32	0.45	3.02	46	74	-	-	0.06	40	48	-	-	0.02	38	-	-	0.16	BRKR	--	No smoke out bldg vent. FC cleared in 6 min.
43	A.4-A.2.2-A.1.1.1	3000	FC	3	ON	ON	OPEN	YES	-3	21	-	-	0.19	20	-	-	0.11	11	0.31	0.43	3.92	45	74	-	-	0.07	43	48	-	-	0.04	39	-	-	0.08	BRKR	--	FC cleared in 6 min.
44	A.4-A.2.1-A.1.1.1	3000	BRKR	2	see	#20	CLSD	YES	3	10	1.07	-	0.00	12	-	-	0.23	14	1.48	3.06	0.95	46	72	0.30	0.32	3.88	39	41	1.31	1.62	14.88	39	0.69	0.92	5.37	CABLE	0.43	FC still smokey after 4.5 min.
45	A.4-A.2.1-A.1.1.1	3000	BRKR	1	ON	ON	CLSD	YES	4	10	-	-	0.09	11	-	-	0.17	14	0.98	1.81	0.51	43	72	0.36	0.16	5.00	39	44	0.82	1.66	8.52	38	0.63	0.71	2.14	CABLE	0.70	---
46	A.4-A.2.1-A.1.1.2	3000	BUS	1	see	#20	CLSD	YES	3	13	-	-	0.14	16	0.51	-	0.14	12	4.73	-	0.19	44	71	-	-	0.01	41	45	0.00	0.02	4.69	38	-	0.54	9.92	BRKR	--	Smoke out of BUS compartment hinge joints and out of top "hat" of CABLE compartment.
47	A.4-A.2.1-A.1.1.2	3000	BUS	1	ON	ON	CLSD	YES	0	2	-	-	0.03	5	-	-	0.10	11	0.90	-	0.44	40	71	-	-	0.02	40	45	0.00	0.00	3.65	35	0.48	0.40	9.77	BRKR	--	Smoke poured out of CABLE compartment top hat.
48	A.4-A.2.1-A.1.1.2	3000	CABLE	1	see	#20	CLSD	YES	-2	20	-	-	0.04	22	-	-	0.04	15	2.43	-	0.54	46	74	-	-	0.04	40	45	-	N/A	0.04	39	0.32	0.06	4.90	BRKR	--	---
49	A.4-A.2.1-A.1.1.2	3000	CABLE	1	ON	ON	CLSD	YES	-3	0	-	-	0.12	3	-	-	0.07	13	0.70	1.11	0.35	41	73	-	-	0.09	41	47	-	N/A	0.00	39	0.35	0.31	6.88	BRKR	--	Smoke poured out of CABLE compartment top hat.
50	A.4-A.2.1-A.1.1.2	3000	CABLE	1	see	#20	CLSD	NONE	-3	21	-	-	0.06	22	-	-	0.00	15	1.71	2.21	0.59	35	70	-	1.76	0.01	39	46	-	N/A	0.14	35	0.23	0.10	9.36	BRKR	--	Same as above.
51	A.4-A.2.1-A.1.1.2	3000	CABLE	1	ON	ON	CLSD	NONE	-3	5	-	-	0.03	7	-	-	0.52	16	0.63	0.91	0.56	29	66	-	-	0.02	38	45	-	N/A	0.00	36	0.14	0.28	12.47	BRKR	--	Same as above.
52	A.4-A.2.1-A.1.1.2	3000	BUS	1	see	#20	CLSD	NONE	-3	7	-	-	0.04	11	-	-	0.07	15	3.98	-	0.06	29	64	-	-	0.08	37	44	0.26	N/A	5.11	34	0.23	0.53	9.05	BRKR	--	Smoke poured from rear H/C vents and hinges.
53	A.4-A.2.1-A.1.1.2	3000	BUS	1	ON	ON	CLSD	NONE	-2	17	-	-	0.06	19	-	-	0.07	13	0.80	-	0.34	30	62	-	-	0.06	35	44	0.18	N/A	6.49	32	0.36	0.43	11.24	BRKR	--	Same as above.
54	A.4-A.2.1-A.1.1.2	3000	BRKR	1	see	#20	CLSD	NONE	-4	22	N/A	N/A	0.04	26	N/A	N/A	0.07	17	N/A	N/A	0.58	33	62	N/A	N/A	8.49	39	44	N/A	N/A	1.32	37	N/A	N/A	0.43	CABLE	0.90	Smoke out of BRKR top hat vents.
55	A.4-A.2.1-A.1.1.2	3000	BRKR	1	see	#20	CLSD	NONE	-3	21	-	-	0.09	25	-	-	0.10	17	1.64	1.94	0.73	33	63	0.15	0.16	8.41	39	45	1.26	N/A	2.37	38	1.16	2.37	0.41	CABLE	0.55	Trace of smoke in FH.
56	A.4-A.2.1-A.1.1.2	3000	BRKR	1	ON	ON	CLSD	NONE	-2	1	-	-	0.02	4	-	-	0.00	15	0.60	0.73	0.45	20	63	0.00	0.00	10.74	38	45	0.61	N/A	2.07	36	0.73	0.55	1.05	CABLE	0.80	FC cleared after 4 min.; smoke out of top vents.
57	A.4-A.2.1-A.1.1.1	3000	FH,RH	3	ON	ON	breaker CLSD	pressurized	5	10	0.26	0.26	1.73	14	0.65	0.73	1.50	20	1.06	1.61	1.54	32	67	0.41	0.38	1.73	41	48	1.57	N/A	1.14	41	1.19	1.69	1.00	CABLE	1.95	FH cleared in 4.5 min.; FC cleared in 5.5 min.
58	A.4-A.2.2-A.1.1.1	3000	FC	3	see	test	#57		5	7	-	-	-	10	-	-	-	17	0.33	0.38	-	28	65	-	-	---	38	47	-	N/A	---	35	-	-	--	CABLE	--	Pressurizing didn't work.
59	A.1.1.1	0	FH,RH,FC	2	OFF	OFF	CLSD	NONE	5	8	1.3	0.77	11.11	10	0.98	2.65	6.18	10	2.47	1.22	3.00	11	-	-	-	0.10	12	-	-	-	0.02	13	-	-	0.64	BUS	--	Smoke poured out of structure due to wind.
60	A.4 (SUPPLEMENTARY)	0	FH,RH,FC	2	OFF	OFF	OPEN	NONE	7	10	1.5	1.35	11.66	12	0.66	0.83	9.99	9	0.86	0.86	3.09	11	-	-	-	0.13	12	-	3.67	-	0.07	13	-	-	0.06	BUS	3.5	Wind drew smoke out of blow-out vent.
61	A.5 (SUPPLEMENTARY)	0	FC	2	OFF	OFF	OPEN	NONE	11	10	-	-	0.02	12	-	-	0.03	9	0.96	1.38	3.16	11	-	-	-	0.01	11	-	-	-	0.07	13	-	-	0.09	BUS	3.5	Same as above.
62	A.3 (SUPPLEMENTARY)	3000 set-up (no 1)	FH,RH	3	OFF	OFF	CLSD	NONE	8	10	1.05	0.83	2.76	12	4.78	-	0.12	11	1.92	0.83	2.43	11	-	4.38	-	9.74	11	-	-	-	0.03	13	-	-	0.02	BUS	--	Rear smoke candle did not fire.
63	A.2 (SUPPLEMENTARY)	same as #62	FH,RH,FC	3	OFF	OFF	CLSD	YES	13	11	0.57	0.53	16.31	13	0.65	0.82	2.17	12	2.15	2.45	8.75	12	-	-	-	0.68	12	-	2.75	-	0.26	13	-	-	0.04	BUS	2.5	Filters slightly restricted smoke.
64	REPEAT OF #62	SAME	FH,RH,FC	3	OFF	OFF	CLSD	NONE	15	12	0.83	0.73	14.29	12	0.45	1.22	3.55	12	1.73	2.17	2.72	12	-	2.8	4.83	5.80	12	-	2.13	-	0.14	12	-	-	0.27	BUS	3.5	Smoke penetrated metalclad.
65	Burning Polyethylene	1200 set-up (no 1)	FH	5	OFF	OFF	CLSD	NONE	7	8	0.30	0.22	2.42	10	3.12	2.83	-	10	-	-	-	9	-	4.42	4.63	0.03	10	-	4.17	4.50	-	11	-	-	--	--	--	Black soot, less dense but more adhesive.
66	MISFIRE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Test mis-fired.
67	Burning Epoxy	Same as #65	FH	5	OFF	OFF	CLSD	NONE	10	10	1.25	1.07	1.66	11	-	-	-	9	-	-	-	10	-	-	-	0.06	10	-	-	-	-	12	-	-	--	--	--	Same as for test #65.
68	Single Phase Arc #1	24 kA	FC	0.10 sec	OFF	OFF	CLSD	NONE	23	21	-	-	0.35	23	-	-	0.32	20	0.07	0.03	4.33	N/A	N/A	N/A	N/A	0.01	N/A	N/A	N/A	N/A	SIDE COMP. 0.32	21	N/A	N/A	N/A	FH	--	No smoke detected by real time indicator in FH
69	Single Phase Arc #2	28 kA	FC	0.20 sec	OFF	OFF	CLSD	NONE	24	23	-	-	0.15	22	2.06	2.06	0.57	22	0.05	0.03	5.20	N/A	N/A	N/A	N/A	0.10	N/A	N/A	N/A	N/A	SIDE COMP. 0.20	20	N/A	N/A	N/A	FH	--	Same as test #68. Blow-out cover loosely hanging
70	Smoke Candle Simultn	0	FC	6	OFF	OFF	CLSD	NONE	22	22	N/A	N/A	0.04	21	N/A	N/A	0.00	21	N/A	N/A	8.78	N/A	N/A	N/A	N/A	0.01	N/A	N/A	N/A	N/A	SIDE COMP. 0.01	N/A	N/A	N/A	N/A	N/A	N/A	Smoke candle similar to arcing smoke (FUD's) Arc smoke concentrated in FC more than candle. Test showed no passive smoke ingress to RH
71	Three Phase Arcing	28.5 25.8 23.0	BUS	0.17	OFF	OFF	CLSD	NONE	21	20			0.05	20			0.02	20			4.48	N/A	N/A	N/A	N/Z	1.66	N/A	N/A	N/A	N/A	SIDE COMP. 0.07	N/A	N/A	N/A	N/A	FH	--	CABLE & BUS comp. filled with smoke.

Notes: 1. For tests #7-#58 inclusive, the CABLE compartment of the H/C structure was sealed.

2. For all tests up to the 3000 A series. the H/C structure had a filter in the top (roof) vent of the BRKR compartment. All other compartments had flaps. No door filters.

3. The air temperatures shown above represent the averages of temperatures read near the floor and ceiling of the reference compartments.